AQUIFER SYSTEM AND GROUNDWATER RESOURCE POTENTIAL OF GANGA-KALI SUB-BASIN IN PARTS OF ALIGARH-ETAH DISTRICTS, U. P.

THESIS

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Doctor of Philosophy

IN

GEOLOGY

BY

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CERTIFICATE

This is to certify that Mr. Rashid Umar has carried out the investigation on **"Aquifer System and Groundwater Resource Potential of Ganga-Kali Sub-basin in parts of Aligarh-Etah Districts, U.P."** under my supervision for the award of the degree of Doctor of Philosophy of the Aligarh Muslim University, Aligarh. The work is an original contribution to the existing knowledge of the subject.

He is allowed to submit the work for the award of the Ph.D. degree of the Aligarh Muslim University, Aligarh.

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CHAPTER I

INTRODUCTION

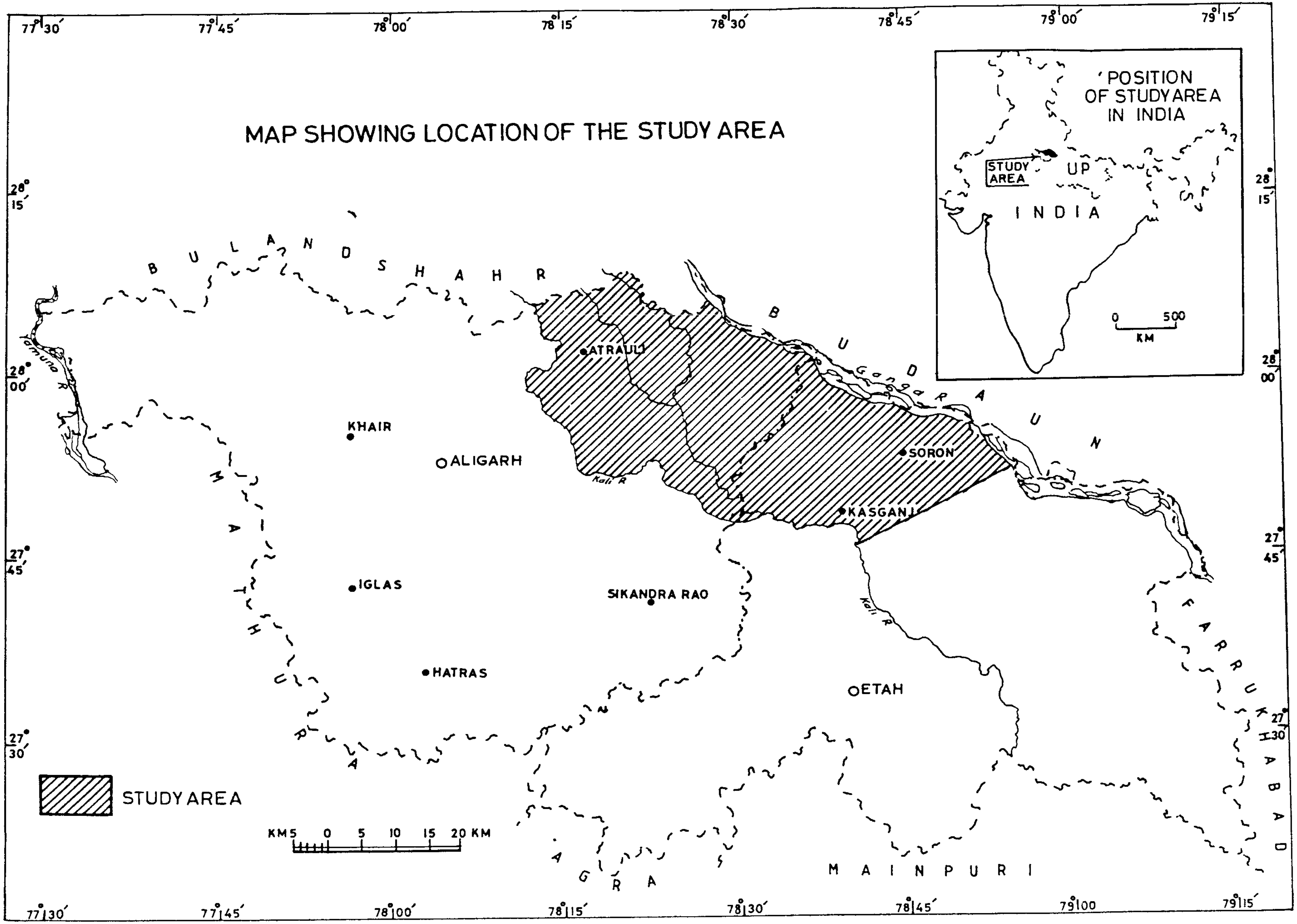
"This (water) marvellous element which can bring life to all things" (Quran), constitutes 71% of the earth surface. The water being so abundant is still a rare commodity, the freshwater which is available for human consumption is only 0.71%. This has necessitated a detailed appraisal of fresh water resources all over the world. The national and international policies on exploration, exploitation and management of water resources have been evolved in order to conserve the scarce freshwater resources and to facilitate its equitable distribution.

India has been well endowed with fresh water resources, but it has spectacle of scarcity with plenty, the quantification of the resource data base has not been done so far which is necessary for optimum utilization and management of the groundwater and surface water in an integrated manner. Efforts in this direction have been initiated by the government, prompted by unprecedented drought and floods in the different parts of the country (Ramesam, 1989).

The Ganga Basin which is literally floating over fresh water underground reservoirs is facing problems for supply of drinking water to some critical areas which has necessiated Water Technology Mission to tackle the problem (Karanth, 1987). In persuance to programme of regional assessment of groundwater the present study was carried

FIG. 1

MAP SHOWING LOCATION OF THE STUDY AREA

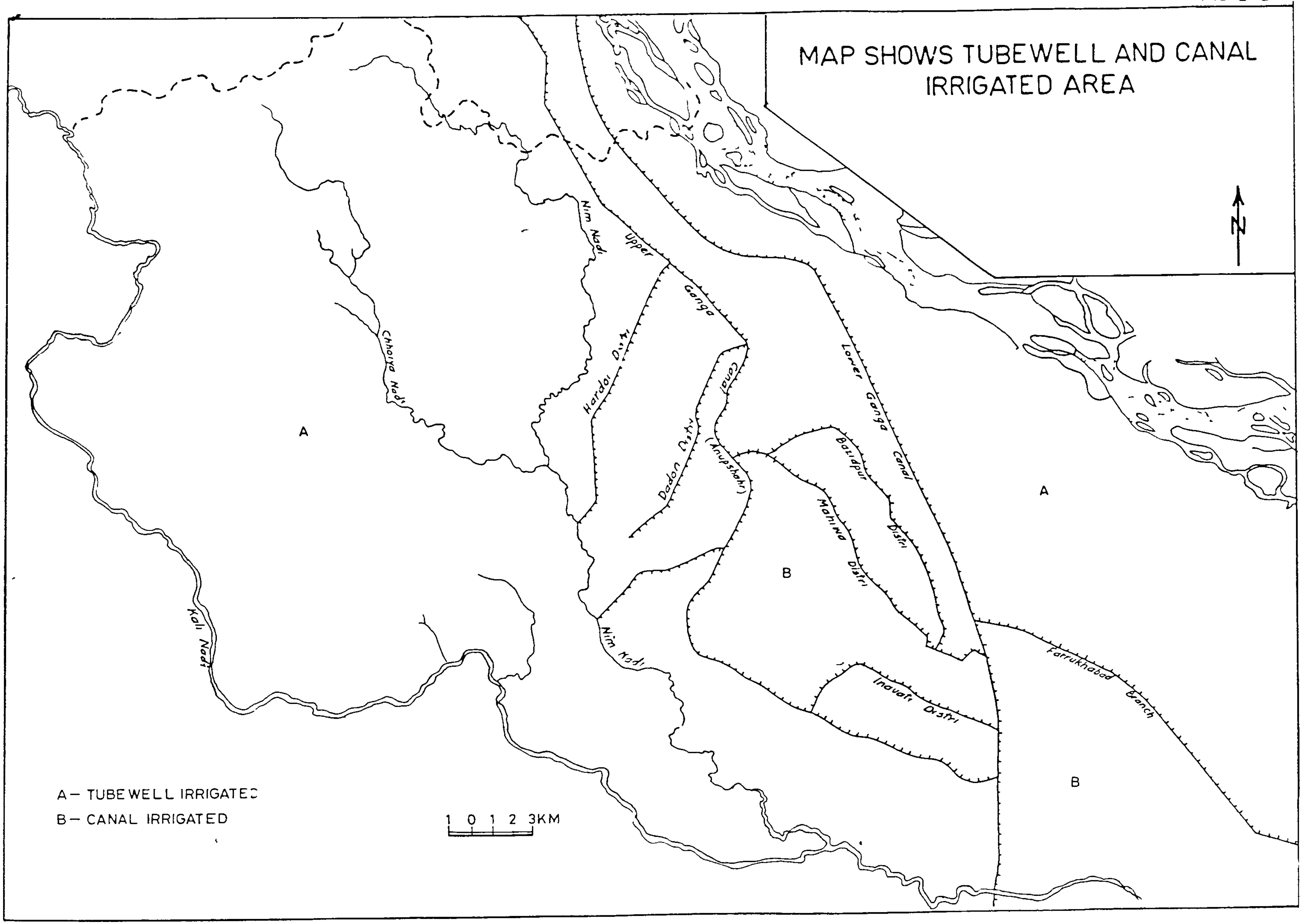


out in Ganga-Kali sub-basin as part of Ph.D. programme, which forms part of the Central Ganga Basin (Fig. 1). The study was directed to evaluate the aquifer system and groundwater resource potential of the Ganga-Kali sub-basin in parts of Aligarh and Etah districts. The choice of the area was made due to its representative character, the basin presents a dual situation that is one of water logging and soil salinisation in canal command areas and depletion of aquifers in western part of the basin (Fig. 2). The quantified data base generated for the Ganga-Kali sub-basin will provide bench mark data for environmental monitoring and hydrogeological management of the basin.

Area : The area is located in the semiarid ecosystem of the Central Ganga Basin. Geomorphologically, it occupies the interfluves between the Ganga and Yamuna flood plain. The Ganga and Kali rivers form the eastern and western limits of the area. Administratively, it is located within Aligarh and Etah districts and is included in parts of survey of India toposheet No. 53L and 54I.

Systematic hydrogeological survey and sampling were carried out in an area of 1340 Sq km covering Latitudes 27°47' to 28°9' N and Longitudes 78°12' to 78°45' E. The area is well connected by rail and road from Aligarh and Etah which are district Headquarters. Almost all the villages are well connected by motorable roads. Atrauli and Kaganj are the important towns in the area with suitable camping facilities.

FIG 2-a



MAP SHOWS TUBEWELL AND CANAL
IRRIGATED AREA
N
Nim Nadi
Upper Ganga Canal
(Anupshahr)
Hardoi Distri
Dadon Distri
Chhoiya Nadi
Lower Ganga Canal
Baiidpur Distri
Mahiwa Distri
Inavati Distri
Farrukhabad Branch
Kali Nadi
A
B
A
B
A – TUBEWELL IRRIGATED
B – CANAL IRRIGATED
1 0 1 2 3KM

Methodology :

In order to generate quantitative data base on hydrogeological parameters and hydrochemistry, systematic groundwater surveys were carried out supported by laboratory investigations.

(i) The literature pertaining to study area was collected and background information on the state of art was generated.

(ii) Toposheet and LANDSAT imageries of the study area were consulted to generated base map for the field survey. The LANDSAT T.M, F.C.C. relevant to the area were interpreted and various land forms were demarcated.

(iii) Rainfall data and various hydrological data pertaining to the area were collected. The rainfall data were analysed and the mean, standard deviation coefficient of variation and occurrence and frequency of droughts were determined for the period 1901 to 1989.

(iv) The reconnaissance survey of the area was carried out with selective ground checks. A network of 160 observation wells was established. The wells were located in such a way so as to cover 4 Sq. km. cells per well. Hydrogeological data and groundwater samples were collected from the observation and other wells in the area.

(v) Repeat measurements to monitor the changes in water level, for pre and post monsoon water level were made during 1988 and 1989.

(vi) The aquifer material (sand samples) were collected from various drilling sites and also from the river Ganga and the Kali beds through trenching. The aquifer materials were mechanically analysed and data obtained were plotted on grading curve and various parameters like effective grain size, sorting coefficient and hydraulic conductivity were determined.

(vii) Pumping test were conducted at two different sites to determine the aquifer characteristic i.e. storativity, hydraulic conductivity and transmissivity.

(viii) In all, 87 groundwater samples were collected from different groundwater structures like open wells, shallow and deep tubewells in duplicate to see vertical and lateral variation in quality. One group of sample was kept for physicochemical examination while the others were immediately acidified with 10 ml 6N HNO_3 and kept for trace element studies. To study the chemical quality of surface water bodies and its inter-relationship with groundwater samples were also collected from the Ganga, Kali and lower Ganga Canal.

(ix) Lithological logs of deep tubewells in the area were collected and fence diagram and various cross sections of the study area were prepared.

(x) The hydrogeological data of dug wells were processed, plotted and interpreted. Various maps like depth to water map, water table contour maps and water level fluctuation maps were prepared. Hydrographs for a period of 15 years were prepared to analyse the changes in the groundwater regime in time and space.

(xi) Water samples were analysed for major and trace elements to determine its quality for domestic and irrigation uses. Various hydrochemical facies were determined through trilinear diagram.

(xii) Concurrence and synthesis of hydrogeological, hydrological, hydromorphological, hydrometeorological, hydrochemical data was attempted to generate the model for groundwater regime of Ganga-Kali sub-basin presented in the present thesis.

State of Art :

The series of developments in hydrogeology between 1856 and 1955 helped to establish the principles of groundwater resource evaluation.

Darcy (1856) did experimental work on the flow of water in sand and derived formula known as Darcy's law, which expresses the relationship between the velocity of percolaton, permeability of water-yielding material and hydraulic gradient, Darcys law serves as the basis for subsequent attempt on quantification of groundwater resource.

Theim (1906) developed an equation for steady state flow conditions of groundwater. Theis (1935) gave the non-equilibrium formula for unsteady state flow to a well discharging from a confined aquifer. Several workers since then have formulated equations relating to discharge from an aquifer to the head difference under the different conditions like leakage from overlying aquitard, delayed yield, large diameter wells, multi aquifer system etc. (Jacob, 1946; Boulton, 1963; Huntush, 1956; Walton, 1962; Pricket, 1965).

The last three decades have seen phenomenal growth in the science of hydrogeology. It is now not limited to resource aspects and hydrodynamics but encompasses physico chemical relations and responses, occurrence, movement and energy storage in the aquifers. Besides, the resource potential, the area is looked into its entire vertical profile from atmosphere to Lithosphere (Ramesam, 1987).

Development of information system and computerized groundwater data bases with telemetric link to ground instruments on real time basis, studies on recycling of resource, Krigging techniques for evaluating regional variable out of sparse data and groundwater modeling using finite difference and finite element models to solve groundwater flow and solute transport problem etc. are some of the modern fields in groundwater research (Marsily, 1986; Bear, 1987; Ramesam, 1987).

Systematic groundwater exploration was taken up in early fifties by the Central Groundwater Board, in India was initially confined to resource evaluation in the unconsolidated formations. The activity extended to the hard rock regions about 20 years latter . *The techniques of exploration primarily consisted of geological* reconniasance, occasional geophysical survey and actual drilling. Today resource estimation at microlevel for some of the river basins through water budgeting studies are available (Ramesam, 1987).

Co-incidental with the water balance studies a few research project of problems specific or location specific nature have been under taken (Ramesam, 1987). In recent years monitoring of the effects of the withdrawls on the groundwater levels and regional decline in water levels has been gaining importance (Rao, 1986).

A concerted thrust on Research and Development in Groundwater with identified areas of research duly supported by requisite budget allocations however has been lacking. As the country is marching towards 21st century by which time the total annual replenishable recharge from rains to the groundwater body would have been fully utilized, the conservation of existing finite resource, its augmentation protection and judicious exploitation would require urgent attention.

Previous work in the Area :

Prior to the present investigation various agencies had undertaken hydrogeological investigations of the study area for different purposes.

The exploratory tubewell organisation , carried out exploratory drilling and short duration pumping tests in Atrauli area, (Anon, 1964), which indicate that transmissivity range from 636.48 to 2327 m^2/day and the storage coefficient varies from 3.17×10^{-3} to 3.9×10^{-2}.

Rao et al. (1965) carried out exploratory drilling and also determined the aquifer parameters through pumping tests at Tikta Village. They reported the value of transmissivity as 914.55 m^2/day and specific yield value 8.75 percent.

Dutt (1969) studied the hydrogeology and water logging conditions in Aligarh district. He reported that the seepage from the Ganga canal has created water logging conditions in the area. He also conducted short duration pumping test in Atrauli area and determined the value of Transmissivity and permeability as 576 m^2/day and 22.2 m/day respectively.

In Bijauli area three to four-tier aquifer system occurs down to the depth of 143 m b g 1. These aquifers laterally merge with each other and behave as a single aquifer system; upto 1986 only 42% of total groundwater resources of Bijauli block had been developed (Ahmad et al., 1989).

Specific yield estimation at Charra village using radio active tracer techniques were carried out simultaneously. Pump test and grain size analysis were attempted to compare the results. The transmissivity and permeability values obtained through radio-active tracer techniques, the puming test and grain size data analysis are in agreement and exhibit general correlation. However, the values of specific yield obtained by grain size analysis slightly differ with results obtained through the pumping test and radio-active tracer techniques (Raja et al., 1989).

Present Work in the Area :

The geomorphology, geology, hydrogeology, hydrochemistry and water balance studies of the area have been described under the present study to provide quantitative data base.

The geomorphological studies have helped in delineating various land forms such as paleo channels, meander Scroll, scars etc.

Geologically, the area comprises quaternary alluvium. The Neogene Siwaliks sandstone occurs as sub-crop at 360 metres b.g.l. and forms good aquifer zone between 360-410 metres b.g.l. Below 410 m the groundwater is saline in nature. The Siwalik sandstone unconformably overlies the Upper Proterozoic Bhander Limestone of Upper Vindhyan Group which in turn directly overlies the Bundelkhand granitic massif at a depth of 2062 below ground level.

Hydrogeologically, the area has two to three-tier aquifer system down to 150 meter b.g.l. which laterally merges into single bodied aquifer system. The study shows that the aquifer upto 90 meter depth are unconfined and below 90 meter they are confined in nature.

The grounnd-water of the basin is potable, hard, alkaline in reaction and moderately mineralised. It is alkali bicarbonate type, suitable for drinking and irrigational purposes. However, the results of chemical analysis show that the groundwater from the shallow aquifers is having concentration of heavy toxic trace elements (slightly higher than the permissible limit which may prove detrimental to human health.

The water balance studies indicate availability of surplus groundwater resources of 169.4 M.C.M. in 1340 square Kilometre basinal area, capable of supporting 588 deep and 3670 shallow tubewells in addition to the existing tubewells. Further, it is suggested that the aquifer lying below 150 meter be thoroughly explored both quantitatively and qualitatively to meet the demand for future water supply.

The area has 48% development but still the scenario is that the basin is partly grey and partly white which is due to faulty management and exploitation policies in the area. The present study will provide the bench mark data for environmental monitoring and hydrogeological management of the basin. It will also serve as a standard for modeling the temporal changes in fragile ecosystem of the Ganga basin which is having a potential danger of pollution from Narora Atomic Power Plant which is located about 12 km in the upstream side of the basin and also the petrochemical complexes emerging in the Gangetic Plain.

CHAPTER II

PHYSIOGRAPHY AND DRAINAGE

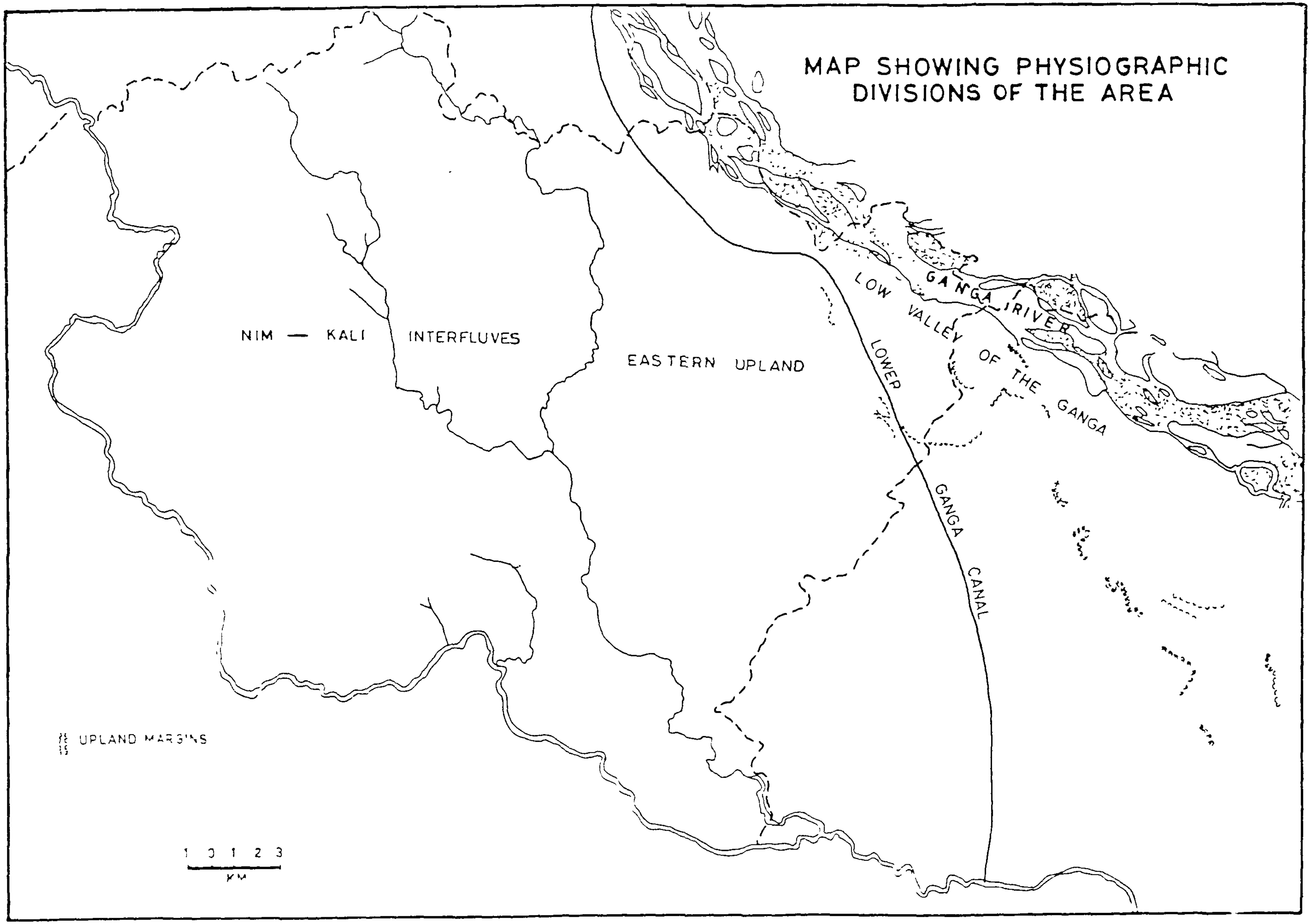
PHYSIOGRAPHY :

The area under investigation is a part of the north eastern sub-divisions of the Aligarh and Etah districts, comprising all the stretches between the Ganga and the left bank of the kali rivers. The latter forms the boundary on the west and south dividing the area from the rest of the Aligarh and Etah districts.

The physical feature of the area presents a great diversity of appearences. From the low valleys of the Ganges which lies between the present active channel and the upland margins, the level rises sharply to the high sandy uplands which crown the old flood bank of the river Ganga and then descends gradually into a depression drained by the Nim and Chhoiya rivers beyond which it rises again to the bank of the Kali-river. Along the right bank of Kali-river is another sandy belt rising from the low valley of the Kali river and this is followed by a belt of loam soil which sinks gradually into the broad central depression further west. Physiographically, the Ganga Kali sub-basin can broadly be divided into the following three distinct physiographic units (Fig. 2 b).

- The low valley of the Ganga
- Eastern upland between the low valley of the Ganga and the Nim river
- Nim-kali interfluves

FIG. 2 - b



MAP SHOWING PHYSIOGRAPHIC
DIVISIONS OF THE AREA
GANGA RIVER
LOW VALLEY OF THE GANGA
LOWER GANGA CANAL
EASTERN UPLAND
NIM — KALI INTERFLUVES
UPLAND MARGINS
1 0 1 2 3
KM

Plate 1. - A view of the Lower Ganga Canal.

PLATE 1

(1) **The low valley of the river Ganga**

It lies between the right bank of the river Ganga and uplands margins. It extends in north west to south east direction parallel to the old bank of the river Ganga. It is 1.6 km wide in north which gradually increases due south where it attains a maximum width of about 16 kilometre, which further south reduces to about 7 kilometre near Soron. The soil of this physiographic unit is recent alluvium comprising fine through medium to coarse sand. Geomorphologically, this tract consist of numerous point bar deposits with enechelon distribution, aligned parallel or sub parallel to the old high bank. They are usually separated by the intervening low land which once form the parts of the erstwhile channels. Each point bar deposit consists of coarsest material at bottom and the finest at the top thus it represents a fining upward sequences.

The lower Ganga canal which is 73.17 m wide and 37 km long with a discharge of 8500 cusec traverses through the eastern margin of the study area (Plate I). The canal flows mainly through the low valleys of Ganga upto Sikandarpur village thereafter traverses along the upland and crosses the kali river near Kasganj through an aquiduct. This canal is a feeder channel out of which Farrukhabad distributary has been taken out which irrigates south eastern part of the study area.

The construction of the lower Ganga canal has greatly benefitted the low valley of Ganga by means of protective embankments

Plate 2a - sand dunes in the low valley of the Ganga.

Plate 2b - Low valleys of the Ganga high land in the background.

PLATE 2 a

which run at right angles to the canal as far as the old channels.

The soil of this valley throughout the area is sandy, differing from the soil of upland. In that they contain a large admixture of vegetable matters. Along the edge of the Ganga are found rich soft loam on which sugarcane is cultivated without irrigation. Similar but less valuable soil is met with along the edge of the old channel of the Ganga. Between the above two, the level lies higher and the quality of soil deteriorates from north to south, being very sandy just above the old channel. South of the old channels, there is always a considerable stretch of very poor soil, either wind blown sand or waste land.

The sub-soil throughout this tract is sand of the Ganges. The surface is everywhere uneven. The crests of the vertical or lateral point bar deposits which are generally aligned enechelon almost sub-parallel to upland margins form the topographic highs while the intervening lows represents the old channels, are mostly found as marshy tracts full of weeds (Plate-II). The point bar deposit are covered with thick forest and form the natural habitat for wild animals.

Eastern Upland:

The low valleys of the Ganga is followed by eastern upland (area between upland margin and the Nim) river which extends in

PLATE 2b

northwest to southeast direction (Fig. 2b).. The eastern flank of this upland slopes towards the Ganga while the western flank tapers towards the Nim-Chhoiya depression- a mini watershed bounded by the Nim and Chhoiya rivers. This upland commences with the belt of high undulating ground above the steep upland margins facing the low flood plains of the river Ganga. The soil of this tract is almost sandy. The ravines are comparatively low and seldom extensive. The sandy tract extends inland as far as the valley of the Nim river. The central portion of this upland is occupied by loam soil and waste land with numerous patches of salt efflorescence. This tract is thickly populated and there are numerous mango grooves. The crest of this upland is traversed by the Anupshahar branch of the Upper Ganga canal and its various distributaries.

Nim-Kali Interfluve :

The Nim-Kali interfluves forms basically the part of eastern upland which has been dissected by perennial stream called Nim hence present physiographic unit is named after Nim-Kali interfluves.

This physiographic unit has further been divided into

(a) Nim - Chhoiya Depression

(b) Atrauli upland

The Nim - Kali interfluves from the largest physiograhic unit of the study area which extends for about 50 km in length from Atrauli in North to Kasganj in south.

Plate 3 - View of confluence of Nim and Kali rivers.

PLATE 3

(a) **Nim - Chhoiya Depression**

The eastern upland is followed by a mini watershed called Nim-chhoiya depression.

This low land appears to have been carved out of the upland through continuous erosion with the passage of time. The Nim enters the area in the north and traverses due south-east and joins the Kali river at Barhari in Etah district (Plate - III). It is a perennial stream but Chhoiya is a drainage channel which joins it at Rumami which remains dry except during the rainy season. There is a belt of low land along the Nim comprising fair quality loam but the soil is apt to deteriorate after heavy floods especially in southern reaches owing to saturation and appearance of salts. The country west of river is a fine stretch of good loam soil extending to sandy ridge which overlooks the valley of Kali river.

(b) **Atrauli upland** :

It is a part of Nim - Kali interfluves. It lies west of Nim-Chhoiya rivers. This part is a stretch of good loam soil which extends westward upto the low flood plain of the Kali river. Almost universally the soil on the immediate margin of the Kali river is a good loam, well raised and not too stiff. This portion is the best and least uncertain portion of the valley. Through the central parts of the Atrauli upland there runs a depression in which soil stiffens into clay and at places there is good deal of waste land, particularly south east of Atrauli.

GEOMORPHOLOGY OF THE AREA

An attempt has been made to identify different geomorphic elements of the Ganga-Kali Sub-basin in parts of Aligarh-Etah districts. For the above purpose, remote sensing data product of LANDSAT TM F.CC bands 2,3,4 pertaining to 145 path and 041 row and 146 path and 041 row were used.

There are two well defined planation (T_2, T_1 surfaces) which have developed in response to changing climate and sea level fluctuations during late Quaternary (Singh, 1987). On these regional planation surface a number of relict drainages, abandoned channels and meander scars are present in contrast to present day active channels (To surface) forming a distinct geomorphic element in the area. T_1 surface from the flood plain of the river about 2-5 m higher than the active channels and represents deposits of past phase of the Ganga.

From the active channel through flood plain to the adjacent uplands, in all three geomorphic surfaces are identified where each one has its own distinctive fluvial geomorphic characters.

To Surface :

The braided stream character and fine sand size of the active channel of the present day Ganga river is T_0 - surface. Here the channel is braided type: a channel which is divided into several

FIG. 3

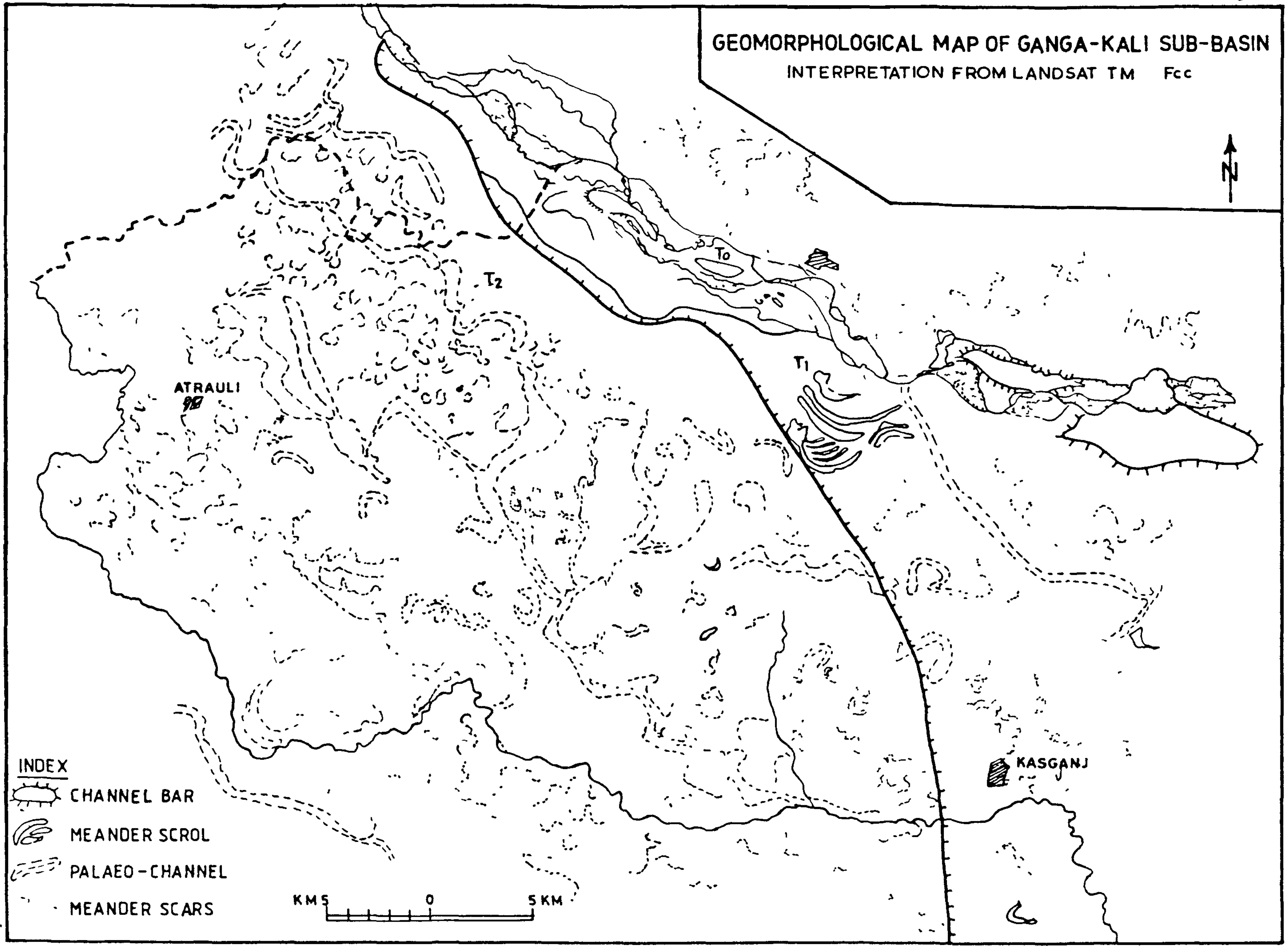

GEOMORPHOLOGICAL MAP OF GANGA-KALI SUB-BASIN
INTERPRETATION FROM LANDSAT TM Fcc
N
T0
T1
T2
ATRAULI
KASGANJ
INDEX
CHANNEL BAR
MEANDER SCROL
PALAEO-CHANNEL
MEANDER SCARS
KMS 5 0 5 KM

Plate 4a - A view of marshy tract at T_1 surface.

Plate 4b - Bushes in the low valley of the Ganga.

PLATE 4

(a)

(b)

channels which successively meet and re-divided. Generally the braiding is low and at bankful stage channel is slightly sinuous. This surface is made up of a few active channels and channel bars (Fig. III).

T_1 Surface :

This surface is located about 5-10 m above the To-surface and restricted within the river valley. The lower gangas canal form the limiting line of this surface. It shows extensive vegetation and number of marshy tracts (Plate - IV). Near surface sediments are silty sand; but below few metres, thick sand deposits are present. In the imagery, this surface shows many meander scars and a very prominent meander scroll close to Sikandarpur village (Fig. 3). Meander scrolls are defined as depression and rises on the convex side of bends formed as channel migrated laterally down the valley and toward the concave bank (Leopold, 1964). Presence of these geomorphic features implies that when the Ganga river was flowing at T_1 surface it was highly sinuous in character. The age of the T_1 surface, abondoned meandering channel is conceptually inferred to be around 20-30 ka, the last inter glacial (Ghosh and Singh, 1988)

T_2 Surface :

This surface is an upland surface, it is 5-10 m above the T_1 surface. Major part of this surface shows silty clay, very often interclated with the calcareous concretions of varying sizes. There are many abandoned drainage and abandoned channels which have given rise to numerous lakes and marshy lands spread here and there all over the area (Fig. 3).

Down to the 10 metres depth below this surface no major sand bodies are encountered during the water well drillings. Age of this surface may be last interglacial (120 ka) upon which tens of metres of sediment have accreted ever since; the age of abandoned drainages is 5-10 ka (Singh, 1987; Ghosh and Singh, 1988). The study shows that the T_1 surface appears in contrast to the braided stream characters of the present day Ganga river To . It is argued that T_1 surface is an older surface and formed by palaeo-Ganga river during 25-30 ka. This palaeo Ganga-River of T_1 surface phase was a higly meandering type, which carried somewhat coarser grained sediment load. It implies that the paleo-Ganga River of 25-30 ka period was carrying more water and less sediment load to distinctive meanders (Singh, 1990).

Mukherji (1963) pointed out from his study of the Ganga-Yamuna interfluves that the paleo-Ganga river was characterised by 8-15 km wide broad river valley as compared to the present day 3-10 km narrow flood plain. This means that in earlier phase the Ganga river was much larger and carrying very higher discharges.. This is further substantiated through the study of the satellite imagery data which show tight meandering of high amplitude demanding a higher water budget during their active phase.

Around 18 ka years back during the last sea-level low stand, the Ganga river cut itself into its T_1 surface as a result of base level adjustment due to fall in sea level, later due to rise in sea level, the Ganga river has aggraded to develope the T_0 surface and this tendency is still continuing. During last 25000 years the Ganga river underwent a distinct change from meandering type to the present day braided type consequent to the decrease in water budget and increase in sediment load (Singh, 1990).

Further, the decrease in the discharge may be attributed to a meteriological and other factors as well. One of the most important factor leading to fall in discharge was the construction of the two feeder canals, one at Hardwar and other at Narora which were constructed in 1879 led to great decrease in discharge amounting to about 11876 cusec. The diversion of such a huge discharge of the Ganga water through these two canals is bound to have its impact on the river behaviour, what happend before 1879 and what factor controlled the fall in discharge are very little known yet the metamorphosis of the drainage from meandering to braided is very well distinct.

DRAINAGE :

The study area under investigation is drained by the Ganga, Nim, Chhhoiya and the Kali rivers. The right bank of the Ganga forms the eastern most hydroboundary. However, the Ganga merely touches the study area in the east and directly drains low of valleys

Plate 5 - Old channels of the river Ganga.

PLATE 5

and a small portion of uplands from which the surface water is carried down by small streams which flow through the few ravines of small magnitude and finally join the Ganga river.

The Old Ganga:

The left over channels of the Ganges are known as the old Ganga. It flows through the low valleys of the Ganga adjacent to the high bank of the upland margins (Plate - V). The flow in the old Ganga channel is slightly sluggish due to the blockade at many places by sand spills and weeds.

The floods in this low valley of the Ganga are common and of long continuance, while the lands in its neighbourhood are liable to water logging.

The Kali River :

The kali river which forms the western hydroboundary of the area is the only tributary of the Ganga which traverses the area. It rises in Muzzaffar Nagar district and passes through Meerut and Bulandshahar, before entering Aligarh district on the northern border close to the Atrauli-Road railway station, then it takes devious but south easterly course, along the southern and western border of Aligarh disttrict passing into Etah near Barhari and forms the southern boundary of the area. The valley through which it flows is deep and about 0.5 kilometer in width from crest to crest and

Plate 6a - Steep left bank of the river Kali.

Plate 6b - Hard pan exposed on the left bank of river Kali.

PLATE 6

(a)

(b)

though stream floods readily, its inundations however, long continued never extend outside the valley. The river is not navigable but of perennial nature and its volume is increased by the surplus water from the Ganga canal. Northern portion of Etah district drains into the Kali river, which is capable of dealing considerable volume of water. It flows mainly through the upland and is characterized by meandering deep channels and highly ravinous banks and finally joins the river Ganga south of Farrukhabad town.

The Nim and Chhoiya Rivers :

The chhoiya being an ephemeral stream, of more importance, however, is only the Nim which traverses through the middle of the Ganga-Kali upland. The stream rises in Bulandshahr district enters the area at Chakathal, flows in southerly or south-easterly direction past the villages of Bijauli, Bhikampur and Gangiri. At a place Rumamai, it is joined on its right bank by a small drainage channel called Chhoiya, which has its source north of Atrauli, close to the district border, and during the rains carries off good deal of water from the low ground in the vicinity. It is dry during the hot weather, but the Nim is perenial, and is utilized for irrigation.

CLIMATE AND RAINFALL :

The Ganga-Kali sub-basin falls under the sub-tropical climatic zone and is characterized by hot summer and chilly winter.

The temperature starts rising by the middle of March, April, May and June are the hottest months of the year. During June the temperature often rises to 45°C while during winter season mercury touches 4°C. December and January are the coldest months of the year.

Rainfall :

The hot spell is followed by the onsets of monsoon which breaks around the 2nd week of June every year. The area receives rainfall mainly from the south west monsoon during the months of June to September. However, heavy precipitation takes place in the month of July and August and monsoon recedes in September. The average annual rainfall for the Ganga-Kali sub-basin is 754. 12 mm.

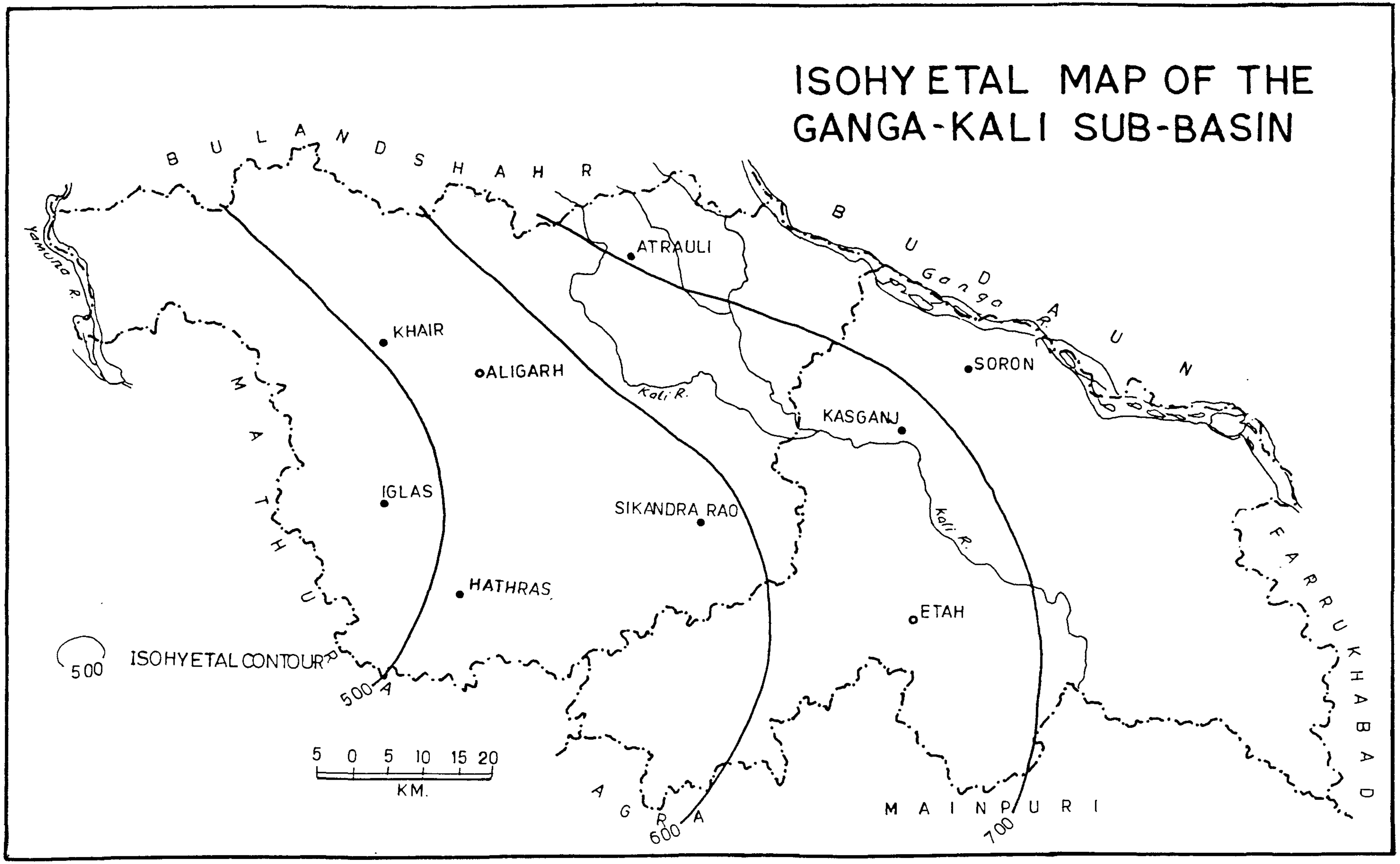
Areal Distribution of Rainfall :

A Perusal of Isohyetal map (fig. 4) of the study area shows that the intensity of rainfall decreases from east to west and on an average the eastern part of the area receives slightly more rainfall which gradually decreases in the west proximal to the bank of river Yamuna.

Departures :

The departure and cumulative departures from the annual rainfall are given in (Appendix IA & B) and are shown in (figure

FIG. 4


ISOHYETAL MAP OF THE
GANGA-KALI SUB-BASIN
BULANDSHAHR
BUDAUN
FARRUKHABAD
MAINPURI
AGRA
MATHURA
Yamuna R.
Ganga R.
Kali R.
Kali R.
ATRAULI
SORON
KHAIR
ALIGARH
KASGANJ
IGLAS
SIKANDRA RAO
HATHRAS
ETAH
500
600
700
500
ISOHYETAL CONTOUR
5 0 5 10 15 20
KM.

5a, 5b & 6a, 6b). The departures show wide variations from the mean, indicating the erratic nature of the rainfall whereas cumulative departures ends around the mean annual rainfall indicating a cumulative compensating effect, as far as the quantum of excess and deficit rainfall over a longer period is concerned.

Variability of Rainfall :

The available annual rainfall data of Atrauli and Kasganj rain-gauge stations for the period 1901 to 1989 have been statistically analysed and results are tabulated (table 1).

The table shows that the highest rainfall at Atrauli rain-gauge station is 1402 mm (1983) where as lowest 307.3 mm (1987) and at Kasganj the highest rainfall 1227 mm (1960) while lowest 208 mm is recorded in 1918, showing a very wide range of variation.

The mean annual rainfall for Atrauli and Kasganj and 755 mm and 753 mm respectively. The average mean annual rainfall for the entire Ganga-Kali sub-basin is 745. 12 mm. The standard deviation at Atrauli is 250.53 and at Kasganj it is 225.43 mm.

The coefficient of variation in the basin varies from 29.93 to 33.18%, minimum and maximum being at Kasganj and Atrauli respectively. This suggests that occurrence of rainfall varies mildly, all over this basin. The average coefficient of variation in the entire basin is 31.5% which is considerably high and indicates a significant variability of rainfall with time.

FIG 5-A

DEPARTURE OF ANNUAL RAINFALL FROM MEAN RAINFALL

(ATRAULI)

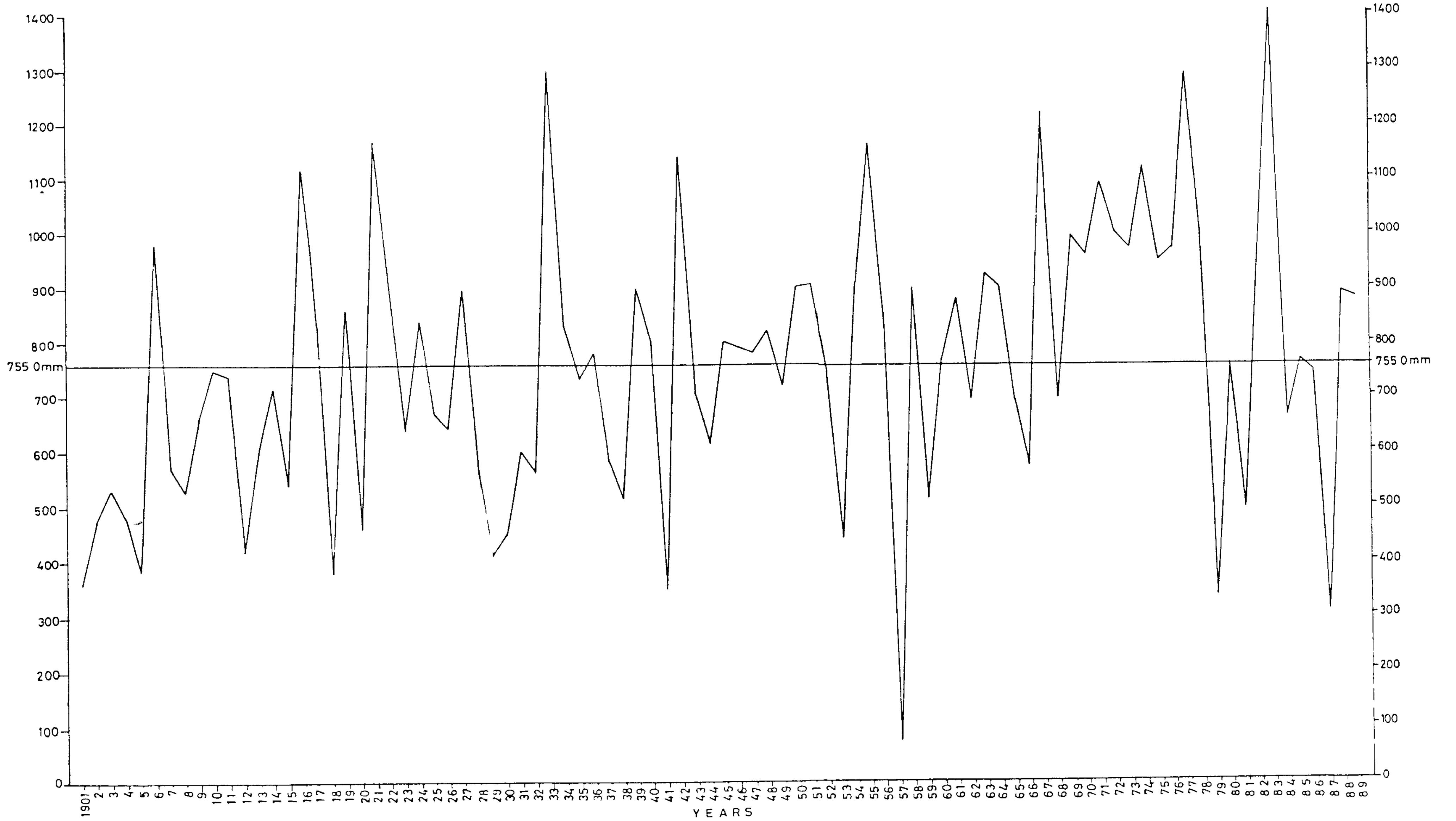


Table 1: Results of statistical analysis of annual rainfall at Atrauli and Kasganj raingauge stations.

Atrauli		
Highest rainfall (1983)	... ...	1402 mm
Lowest rainfall (1987)	... ...	307.3 mm
Mean	... ...	755.06 mm
Standard deviation	... ...	247.4
Coefficient of variation	... ...	33.18%
Kasganj		
Highest rainfall (1960)	... ...	1227.7 mm
Lowest rainfall (1918)	... ...	208.00mm
Mean	... ...	753.19mm
Standard deviation	... ...	225.43
Coefficient of variation	... ...	29.93%

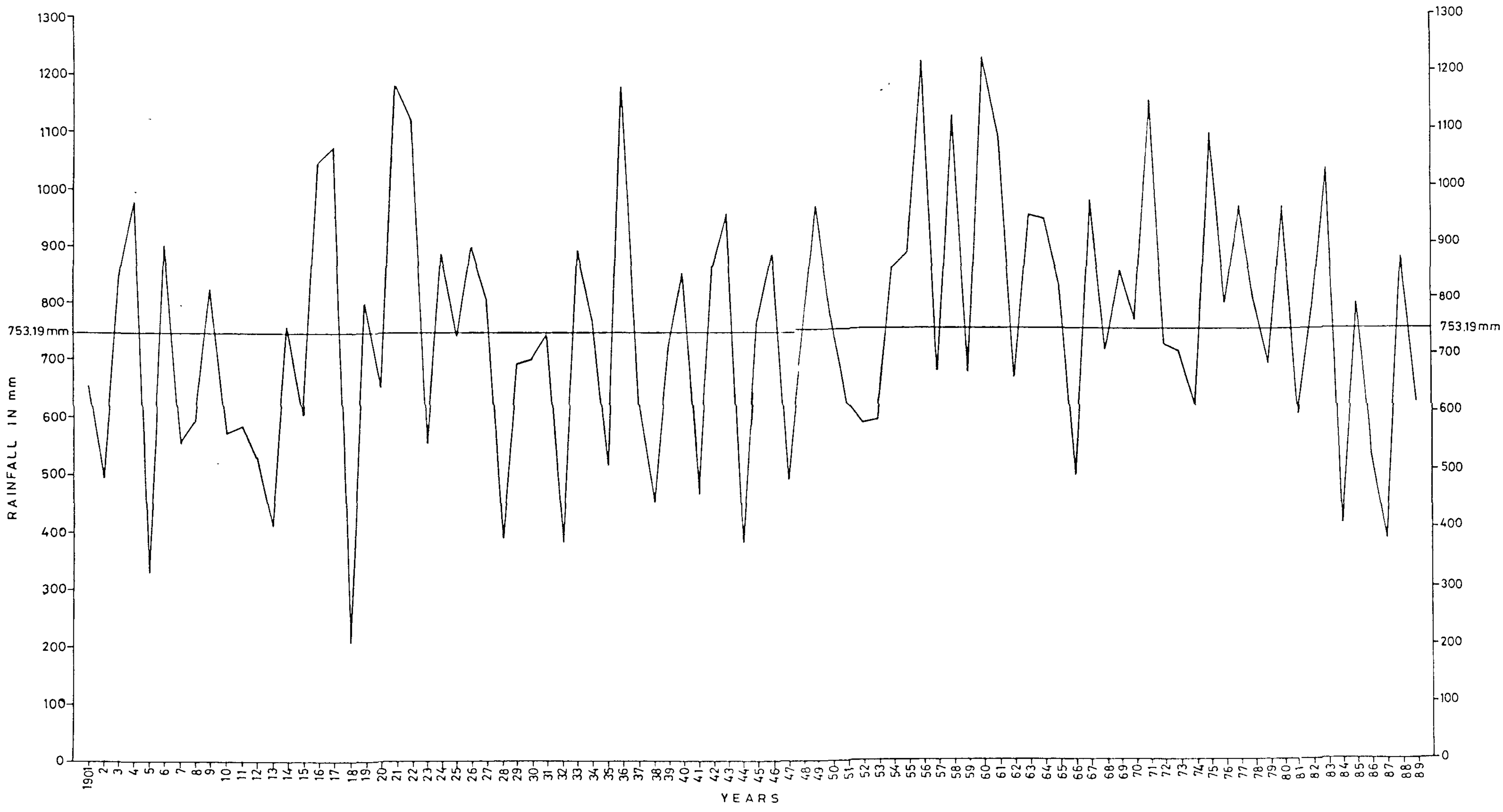
DROUGHT ANALYSIS

Rainfall varies in space and time. Droughts and floods are the consequences of this variability.

In general drought refers to large and prolonged lack of rainfall affecting agriculture, domestic water supplies and other water dependent economic activities. But with the developing techniques of operational management of our water resources, a

FIG. 5-b

DEPARTURE OF ANNUAL RAINFALL FROM MEAN RAINFALL
(KASGANJ)



drought condition has to be viewed from 3 different angle (Upadhya et al., 1989).

(a) **Metorological :**

When the actual rainfall is less than the normal (long term climatological mean) by 25% or more over an area.

(b) **Hydrological :**

When there is marked depletion of surface water and consequent drying up of lakes, reserviors and rivers. It may also result in recession of glacier due to insufficient regeneration of seasonal snow cover.

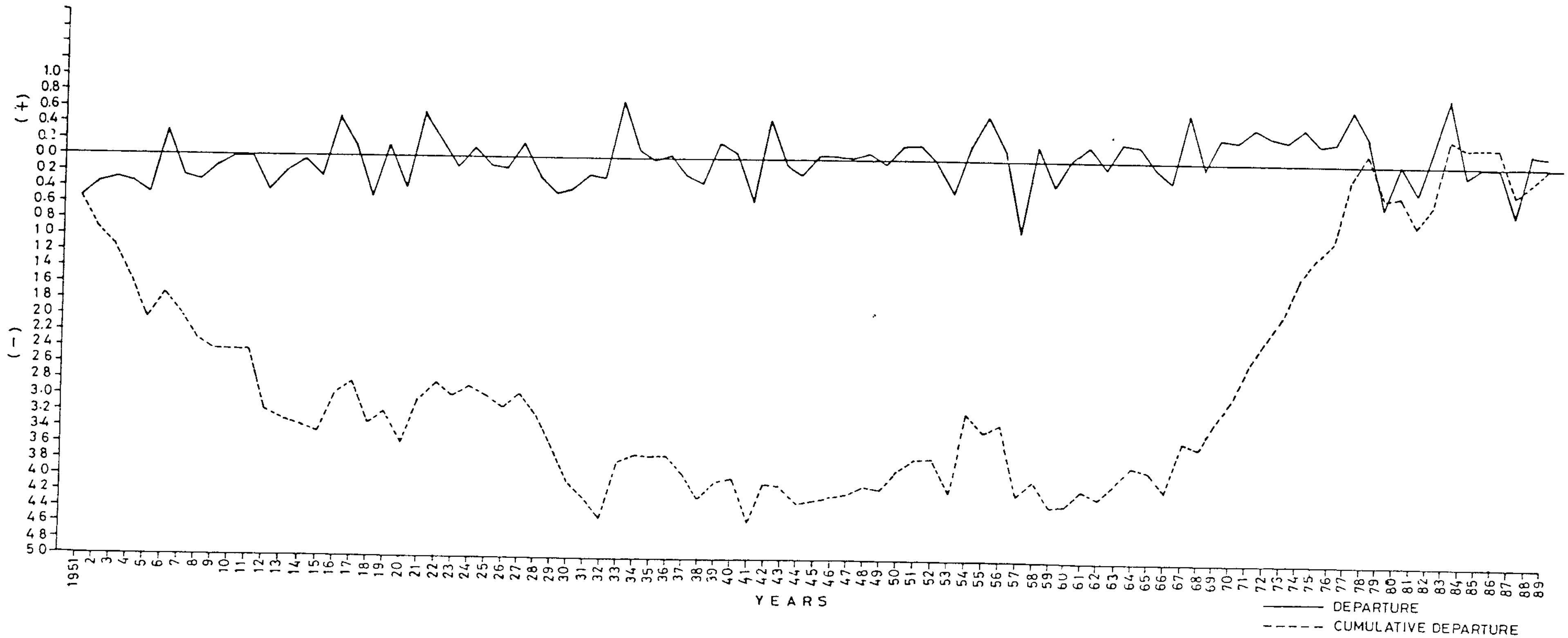
(c) **Agricultural :**

When soil moisture is inadequate to support healthy growth of crops. Water table goes deeper and ground water is unable to meet the demand. The study area forms a part of the central Ganga plain which is basically an agricultural tract, hence the computations are mainly based on agricultural definition of drought. The computation takes into account the negative departure of rainfall from the mean.

The classification of drought based on the percentage of the negative departure of rainfall from its mean are as follows.

FIG. 6-a

DEPARTURE FROM MEAN ANNUAL RAINFALL AND CUMULATIVE DEPARTURE
(ATRAULI)



Percentage of Departure	Type of Drought
0.1 - 25.0	Mild drought
25.1 - 50.0	Normal drought
50.1 - 75.0	Severe drought
75.1 - 100.0	Most severe/rare drought

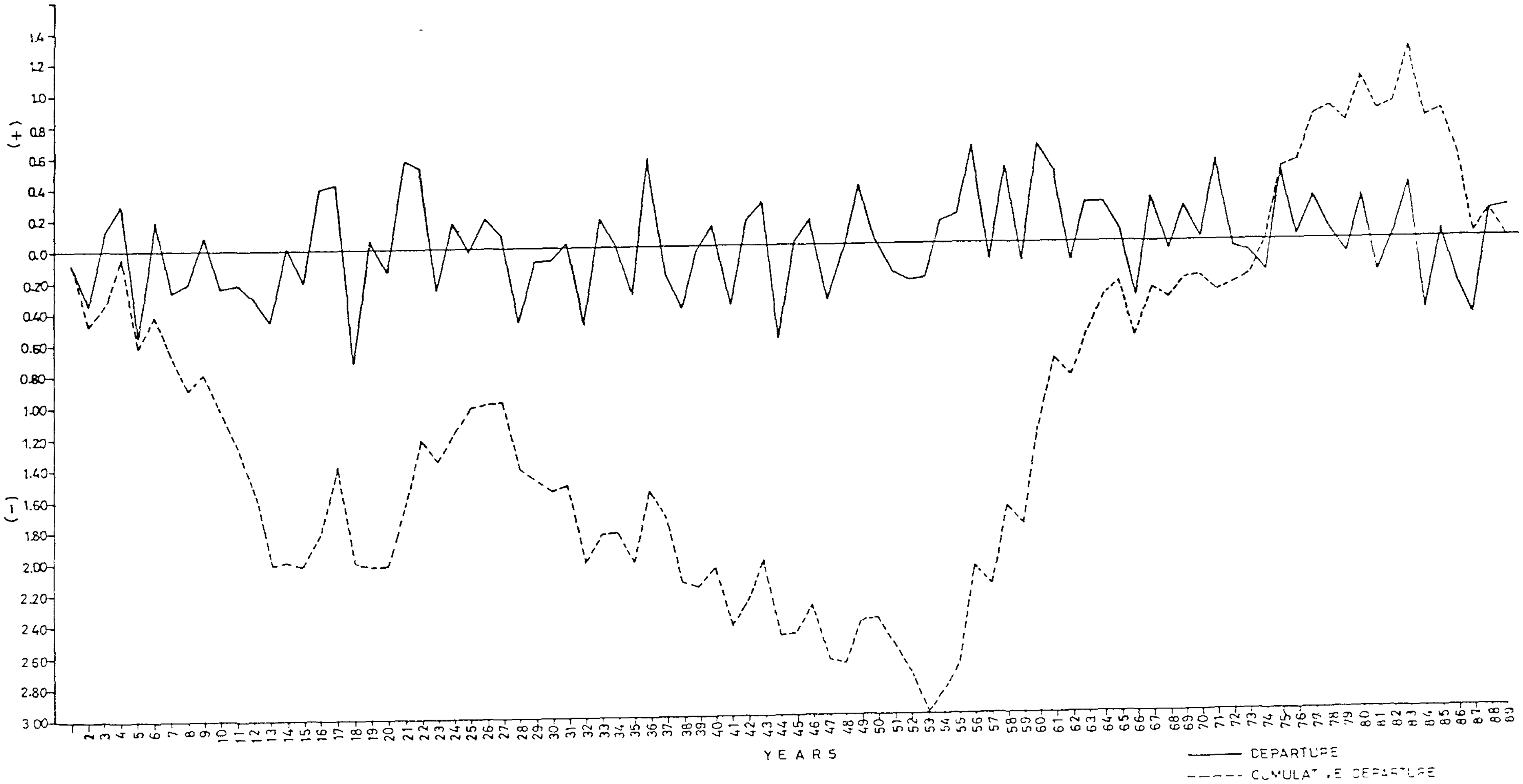
The analysis for drought occurrence in the basin shows that the area in general has been experiencing droughts of varying intensity over the period (1901-1989). The table below shows the year and frequency of occurrence of droughts in the basin.

Table 2a: Result of Drought Analysis at Atrauli

Types of Drought	Years	Frequency of occurrence
Mild drought (0 - 25%)	1907, 1909, 1910, 1911, 1913, 1914, 1923, 1925, 1926, 1928, 1931, 1935, 1937, 1943, 1944, 1949, 1952, 1962, 1965, 1966, 1968, 1984, 1986, 1987	26.96%

FIG. 6-b

DEPARTURE FROM MEAN ANNUAL RAINFALL AND CUMULATIVE DEPARTURE
(KASGANJ)



Normal drought (25 - 50%)	1902, 1903, 1905, 1908, 1912, 1915, 1918, 1920, 1929, 1935, 1937, 1938, 1953, 1959, 1981,	17.97%
Severe drought (50 - 75%)	1901, 1941, 1979, 1987	4.49%

Table 2b: Result of Drought Analysis at Kasganj

Type of drought	Years	Frequency of occurrence
Mild drought	1901, 1908, 1910, 1911, 1915, 1920, 1925, 1929, 1930, 1937, 1939, 1948. 1951, 1952, 1953, 1957, 1959, 1962, 1968, 1972, 1973, 1974, 1979, 1981, 1989.	28.08%

Normal drought (25 - 25%)	1902, 1907, 1912, 1913, 1923, 1928, 1932, 1935, 1938, 1941, 1944, 1947, 1966, 1984, 1986, 1987.	17.97%
Severe drought (50 - 75%)	1905, 1918	2.24%

SOIL TYPE OF THE AREA

The soil survey of the area was carried out by the department of Agriculture, Government of Uttar Pradesh in the year 1953. In all, three types of soils have been reported pertaining to three distinct physiographic units of the basin (fig. 7) which are as under:

1. Sandy loam
2. Sandy loam to loam
3. Loam to clay loam

1. **Sandy Loam :**

The low valley of the ganga is underlain by sandy to silty loam, which this tract receives year after year because of overflowing of the Ganga during flood season.

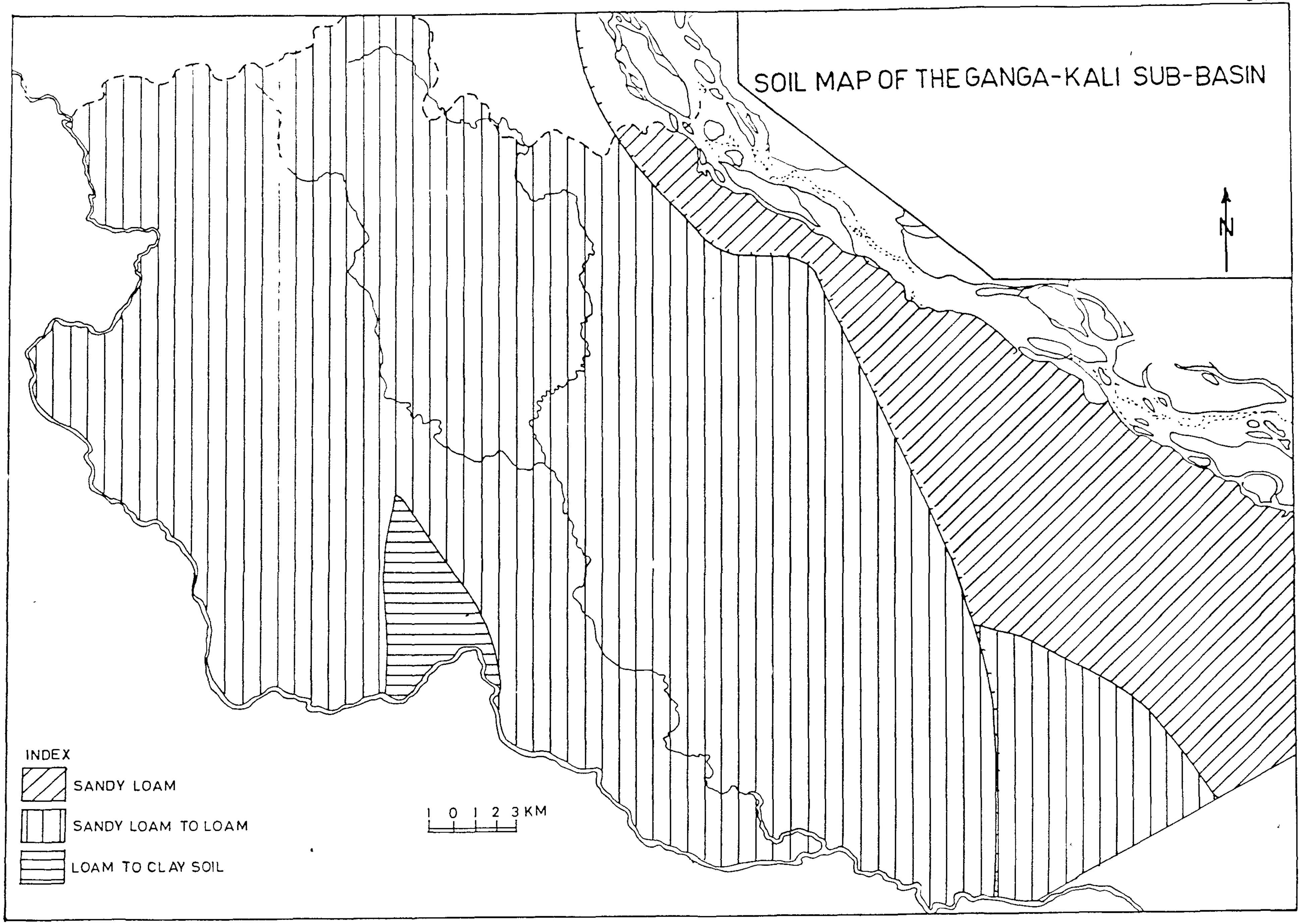
Generally, the deposit is of silty nature with varying colour from light grey to ash grey. The soil is immature and has sandy to silty loam texture.

Consequent to shallow groundwater level salt efflorescence appears to be common feature of the entire tract which are locally called as usar (wasteland). Generally, the soils are alkaline in reaction with a pH usually above 8. The soil profile consists of numerous immature stratified layers of younger soils which deposited over one another during the flood periods of the river Ganga. These soils have fewer reserves of lime, magnesia and iron. The presence of lime saves the soil from becoming completely salinized.

2. **Sandy Loam to Loam Soil :**

This soil type covers the major portion of the upland tract. The soil varies in colour from light brown to dark brown and the texture of the soil is sandy to good quality loam. Generally, the surface soil to a depth of 20 to 25 cm is well drained soil and contains loose loam that can easily be ploughed and cultivated. The soils are more leached than the other soil of the area. The percentage of lime content is low and magnesia is every

FIG 7


SOIL MAP OF THE GANGA-KALI SUB-BASIN
N
INDEX
SANDY LOAM
SANDY LOAM TO LOAM
LOAM TO CLAY SOIL
1 0 1 2 3 KM

where more than the lime. The calcareous nodules occur almost everywhere in the sub-soil. The pH ranges between 6.2 to 6.8

3. **Loam to Clay Loam :**

A small portion of the area between Charrah and the left bank of the Kali river are covered by this soil. This is a sticky and generally clayey loam to loam in texture. The colour varies from grey to dark grey tending to black when moist. The tract is underlain by thick pan of calc concretions occuring in mild cases in the form of nodules which at places cement together forming a stiff impermeable belt in the bottom layers. The percentage of clay decreases with the increase in depth which shows an ideal example of water logged soils where the impermeable sub-soil horizon does not allow the translocation of even the finest clay particles. Due to poor drainage, the soluble sodium salts are deposited on the surface in the form of salt efflorescence (reh). The pH value of the soil ranges from 7 to 9. Iron and Alumina remain stationary and magnesia is little in the entire profile (Agrawala, et al. 1953).

Land use pattern in the Ganga-kali Sub-basin

The statistics pertaining to the land use pattern in the Ganga-kali sub-basin is given in (Table 3).

Table 3: Land use pattern in Ganga-kali Sub-basin (In hectares)

Area	Forest	Cultivable waste land	Present fallow land	Barren uncultivable land	Land under non cultivated use	Pastures	Land under miscellaneous trace and grooves	Net area sown	Area sown more than once
134000	127	60.81	34.27	58.52	143.57	5.85	3.90	104250	81728

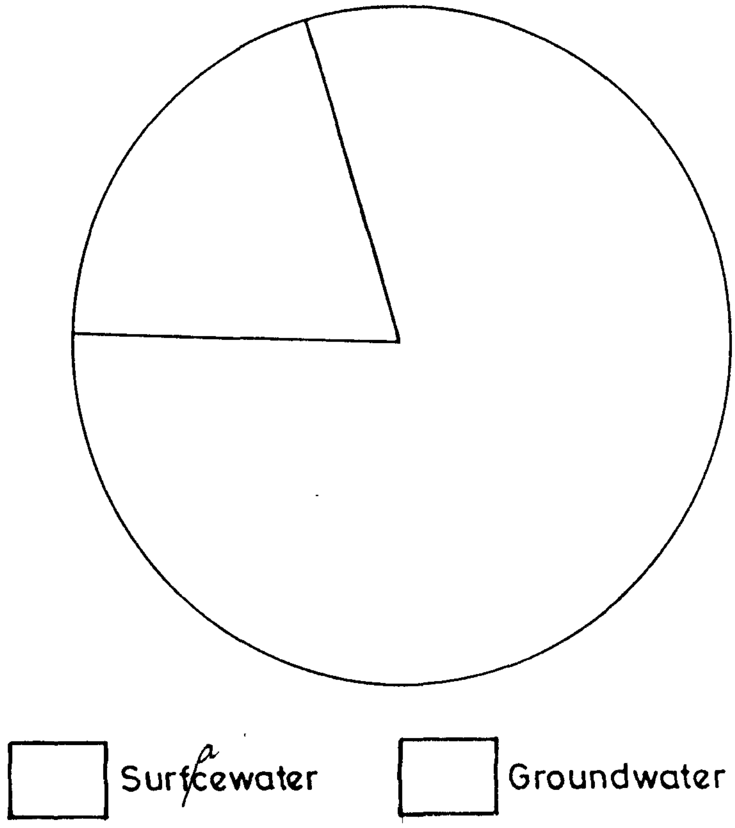
The perusal of table show that out of total area of 134000 hectares, 77% of the area is under cultivation of which 78% is sown more than once. Only 0.09% of the total area is covered by the forest. Rest of the area is covered by the barren and uncultivable land.

Wheat, peanut, potato, groundnut and sugarcane are the major winter crops. Maize, millet, and rice are the important crops which is cultivated during the summer.

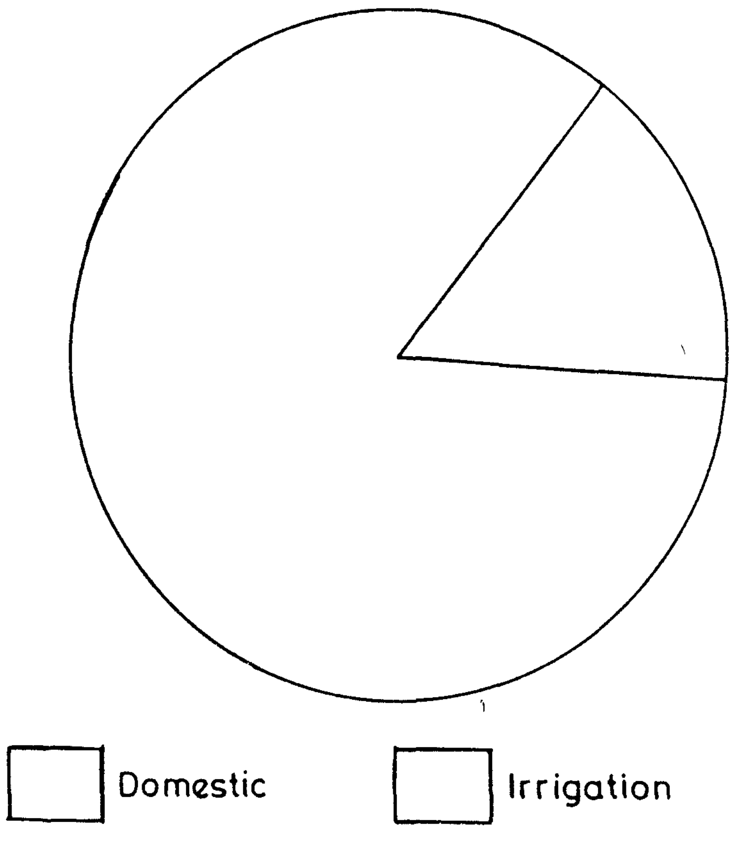
With the advent of the high yielding varities of wheat and paddy the crop pattern is gradually changing. The wheat dominates the winter crops and paddy and millet as the summer crops. Beside it groundnut, potato and sugarcane being cash crops have started attracting the farmers in the area.

Figure - 8

PIE DIAGRAM SHOWING WATER UTILISATION PATTERN



PIE DIAGRAM SHOWING GROUNDWATER USE IN THE STUDY AREA



Water Use Pattern in the Area

Groundwater, is an important source of water supply which is basically a renewable resource, but the volume of water may vary greatly from place to place depending on the climate, regional hydrogeology and rate of groundwater use for agriculture demestic and industrial purposes. The use of groundwater has escalated significantlly worldwide since 1960 (Fletcher, 1986).

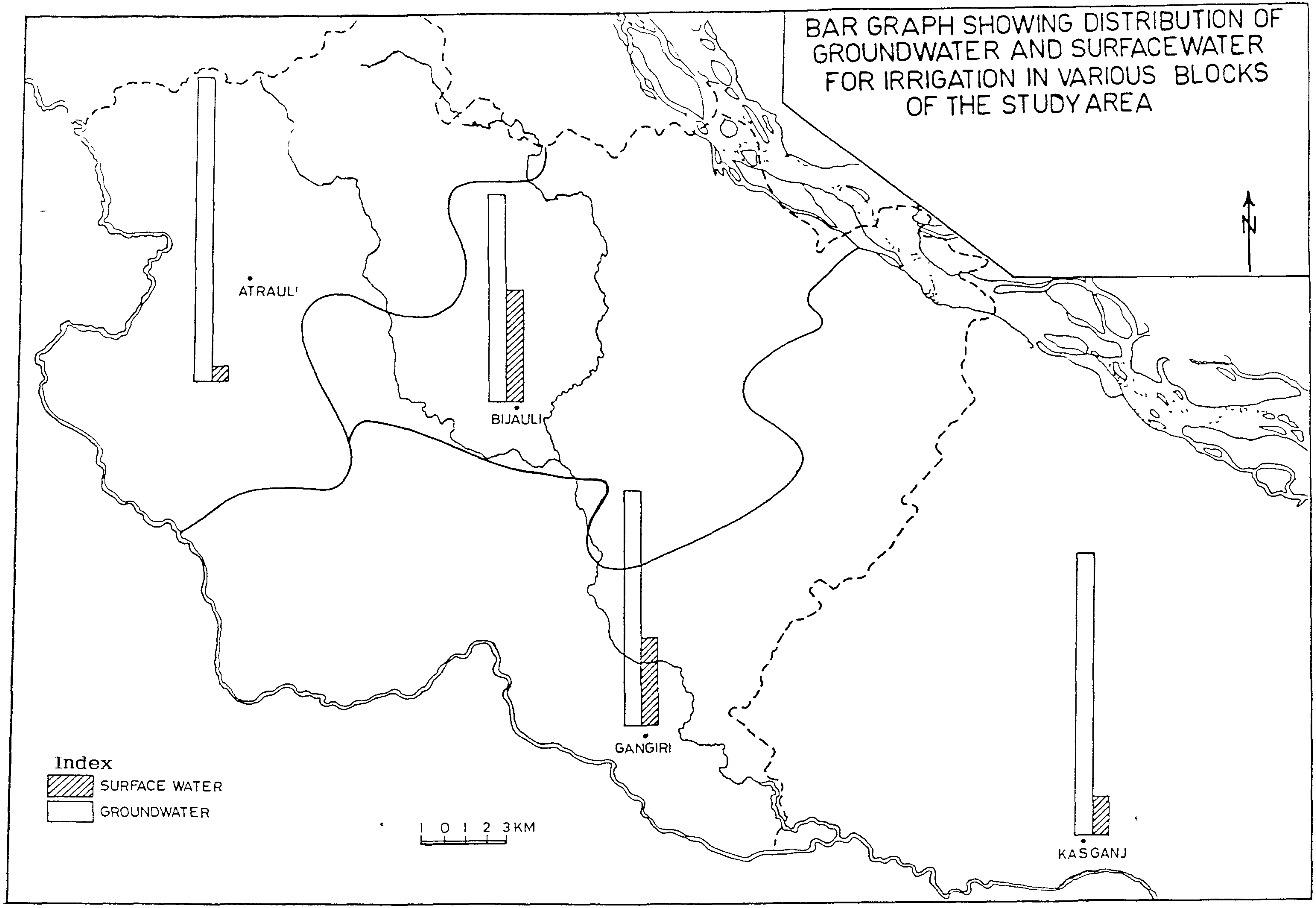
Out of the total water resources of the Ganga-kali sub-basin, 19.8% is derived from the surface water source and 80.2% from the groundwater source (figure 8a). The Anupshaher branch of the upper Ganga canal and Farukhabad distributory of the lower Ganga canal supply the surface water for irrigations mainly for Ganga-Nim interfluves known as the eastern upland and also the area lying west and south-east of Kasganj town.

Administratively, the study area is divided into various integrated developmental blocks and accordingly the water use pattern are furnished as below and shown in (figure 9).

Table 4: Contribution of surface and groundwater for irrigation in different blocks (Anon, 1987)

Blocks	Percent area irrigated by surface water	Percent area irrigated by the Groundwater
Atrauli	5.0%	95%
Bijauli	35.17%	64.83%
Gangiri	26.84%	73.16%
Kasganj	12.10%	87.90%
Average	19.80	80.20

FIG 9



BAR GRAPH SHOWING DISTRIBUTION OF GROUNDWATER AND SURFACEWATER FOR IRRIGATION IN VARIOUS BLOCKS OF THE STUDY AREA
N
ATRAULI
BIJAULI
GANGIRI
KASGANJ
Index
SURFACE WATER
GROUNDWATER
1 0 1 2 3 KM

Estimates of groundwater use of the Kali basin show that out of the total groundwater withdrawn i.e. 169 M.C.M. 85% is used for irrigation purpose and remaining 15% is used for demestic purpose (figure 8b). Water used for rural supply also includes water for livestocks.

CHAPTER III

GEOLOGY

Physiographically, the Indian sub-continent has been divided into three distinct units viz., Peninsular shield, the Himalayas, and the Indo-Gangetic plain (Fig. 10).

Peninsular shield is composed of geologically ancient rocks of diverse origin, most of which have undergone much crushing and metamorphism. Structurally, the Peninsula represents a stable block of the earth crust which has remained unaffected by mountain building movement since close of pre-cambrian era.

The Extra-Peninsula or the Himalayas is a region of folded and overthrust mountain chains of about 65 million years old. Their curvilinear structure is very striking. They consist mainly of circular arcs which are convex towards Peninsula i.e. towards the rigid crust against which they appear to have been thrust (Krishnan, 1968). Though the Extra-Peninsula contains some very old rocks, is predominantly a region in which sediments were laid down in a vast geosyncline continuously from the Cambrian to early Tertiary age.

Apparently, the Himalayas foot hills are separated from the northern border of Indian Shield by a vast plain known as Indo-Gangetic plain, covered by the Quaternary alluvium which forms the major unit in the geology of the Indian sub-continent. It includes the great alluvial tract of the Ganges, Brahamputra and Indus covering an area of 85,0000 square kilometre (Krishnan, 1968).

The Indo-Gangetic plains are broad, monotonous, level expanses built up of Quaternary alluvium, through which the rivers flow sluggishly towards the seas. The Gangetic alluvium effectively conceals the solid geology of its floor.

Earlier, there has been much speculation regarding the sub-surface geology of the Indo-Gangetic plains. The plumb line deflection and gravity data obtained by Survey of India, were too meagre to give any concrete indications of the sub-surface geology. However, with the advent of geophysical exploration in these plains about five decades back, a fairly large volume of data indicating the nature of sub-surface geology and structure has been obtained which was further substantiated by number of deep exploratory wells drilled in these plains by Oil and Natural Gas Commission.

Although, the Indo-Gangetic plain appears as one vast stretch from one end to other geologists have held for a long time the opinion, that the floor of this plain is not an even one but there are hidden ridges and depression which lies under the alluvium (Rao, 1973).

The term "ridge" as applied to the structural features of the Ganga plains refers only to the linear aeromagnetic anomalies and should not be understood in the normal sense of the term. These might have formed important topographic divides at the time of Vindhyan deposition, but subsequently peneplained, and the overlying Siwaliks occur with nearly uniform thickness across the ridges. Similarly the word "basin" applied to areas between these ridges should not be understood as representing truly synclinal depression (Karunakaran et al., 1976).

The most important basic data regarding the basement configuration and sedimentary basin of the Indo-Gangetic plains are provided by Agcos, (1957). Basement depth contours for the whole of Indo-Gangetic plain have also been computed by aeromagnetic data which show that sedimentary section sometimes even exceed 833 metres thickness towards the northern part (Agcos, 1957).

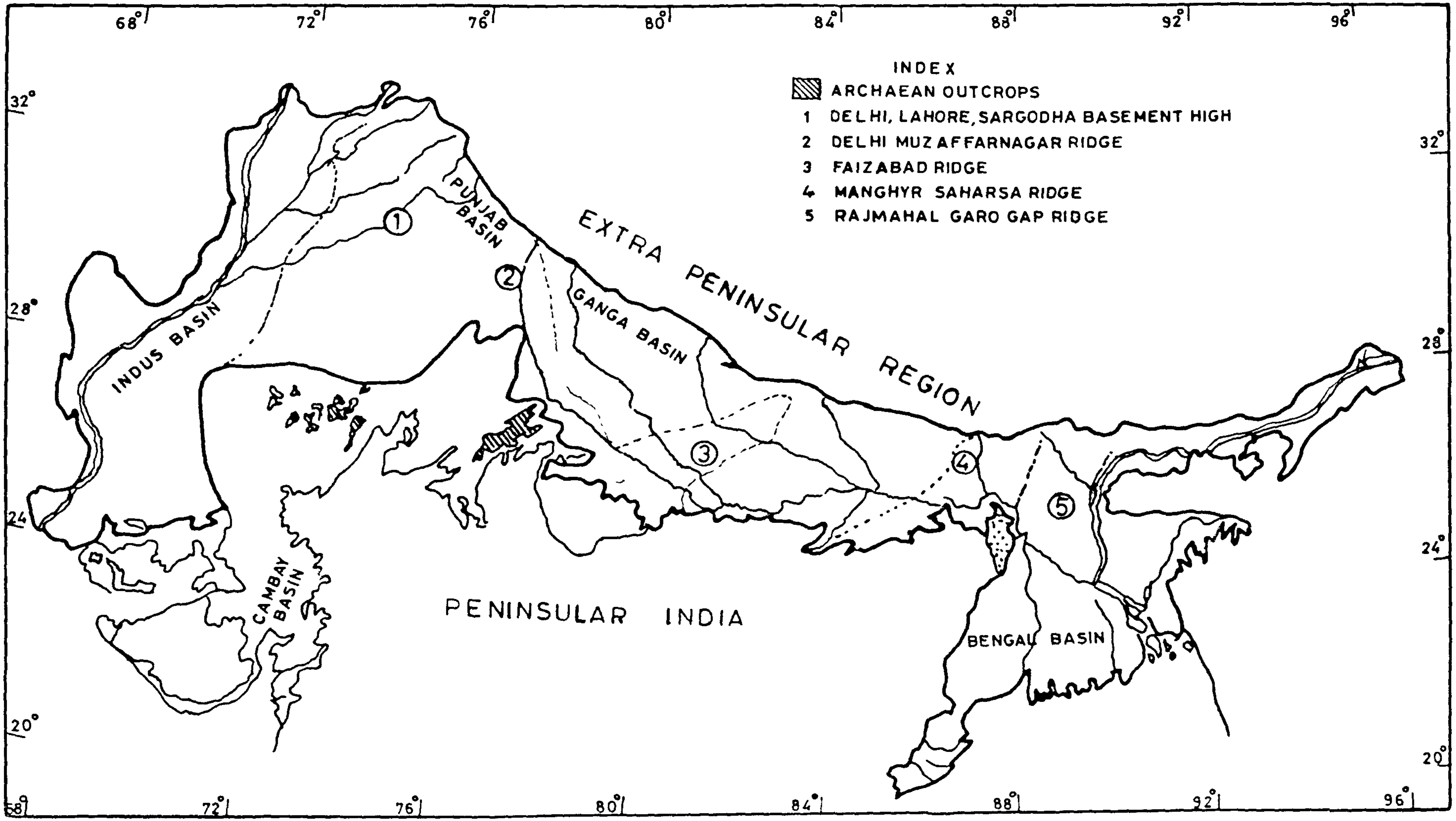
The maximum depth to the basement indicated in seismic surveys in all these plains is about 6 kilometres.

The Indo-Gangetic plain can broadly be divided into the following basins (Fig. 11).

1. Indus basin of Pakistan
2. The Punjab basin
3. Brahmaputra basin
4. Bengal basin which also includes Bangladesh
5. Ganga basin.

MAP OF THE INDO-GANGETIC PLAINS INDICATING THE MAIN DIVISIONS
(THE THICK LINE SHOWS THE BOUNDARY OF THE PLAINS)

FIG. 11



1. **Indus Basin**

The largest part of Indus basin lies in Pakistan. It is filled up by sediments extending back in age from Permo-Carboniferous to Quaternary and possibly also by Vindhyans remnants which are found in western Rajasthan (Krishnan, 1968). The basin is 6000 m deep. A large thickness of Tertiary and Mesozoic Sediments have been met under the alluvium. This thick marine sequence has thinned out towards Rajasthan Platform.

2. **Punjab Basin**

The Archean basement rocks either outcropping or occuring under moderate thickness of alluvium in Lahore-Sargodh area separate the Indus basin in the west from the Punjab depression in the east. The Seismic survey by the O.N.G.C. (Datta et al., 1964) has indicated that the basement surface as well as sediments below the alluvium gently dip towards the foot hills. However, the basement becomes deep as foot-hills are reached with corresponding increase in the thickness of sediments. The maximum depth of basement is 4.5 km (Datta et al., 1964).

3. **The Brahamputra Basin**

The Brahamputra basin of Assam may be divided into western and eastern part lying in between Shillong and Mikir hills and the Himalayan foot-hills has been named as "Northern Shillong Shelf".

The eastern part lying in between Naga Hills and the Himalayas has been named as "Assam Shelf". The western part is shallow in most of the southern portion and near the foot-hills the sediments, mainly the equivalent of Siwaliks attain appreciable thickness. The gravity data indicate steep dip of basement to the north (Ratnam, 1963).

The Ganga Basin

The Ganga basin is the most extensive in the area and comprises more than half of the total Indo-Gangetic Plain. The plain is a great long sedimentary area, flat and monotonous which is drained by the river Ganga and its tributaries.

The western margin of the basin is limited by the Middle Proterozoic Delhi-Hardwar ridge and the eastern margin by the Monghyr-Saharsa ridge of Satpura Metamorphics. To the north, the Ganga basin is limited by outer most Siwalik foot-hills of the Himalayas bounded by series of reverse faults. Along the southern fringes of the basin Bundelkhand granite, Delhi and Upper Vindhyan group of rocks are exposed.

In Uttar Pradesh and Bihar Plains lying between Delhi-Hardwar and Monghyr-Saharsa sub-surface ridges, the Vindhyans of the Peninsular Shield can be followed upto foot-hills into Sarda and Gandak depressions (Karuna Karan et al., 1976). The Ganga basin represents a large scale regional depression on the northern margin of the Indian Platforms and is considered as super order crustal structure of negative character most probably forming a northerly continuation of Vindhyan synclise (Sastri, 1971). The deep bore hole data obtained from Ujhani, Tilhar, and Puranpur suggest the northward continuation of upper Vindhyan sediments into the Ganga basin.

ORIGIN OF THE GANGA BASIN

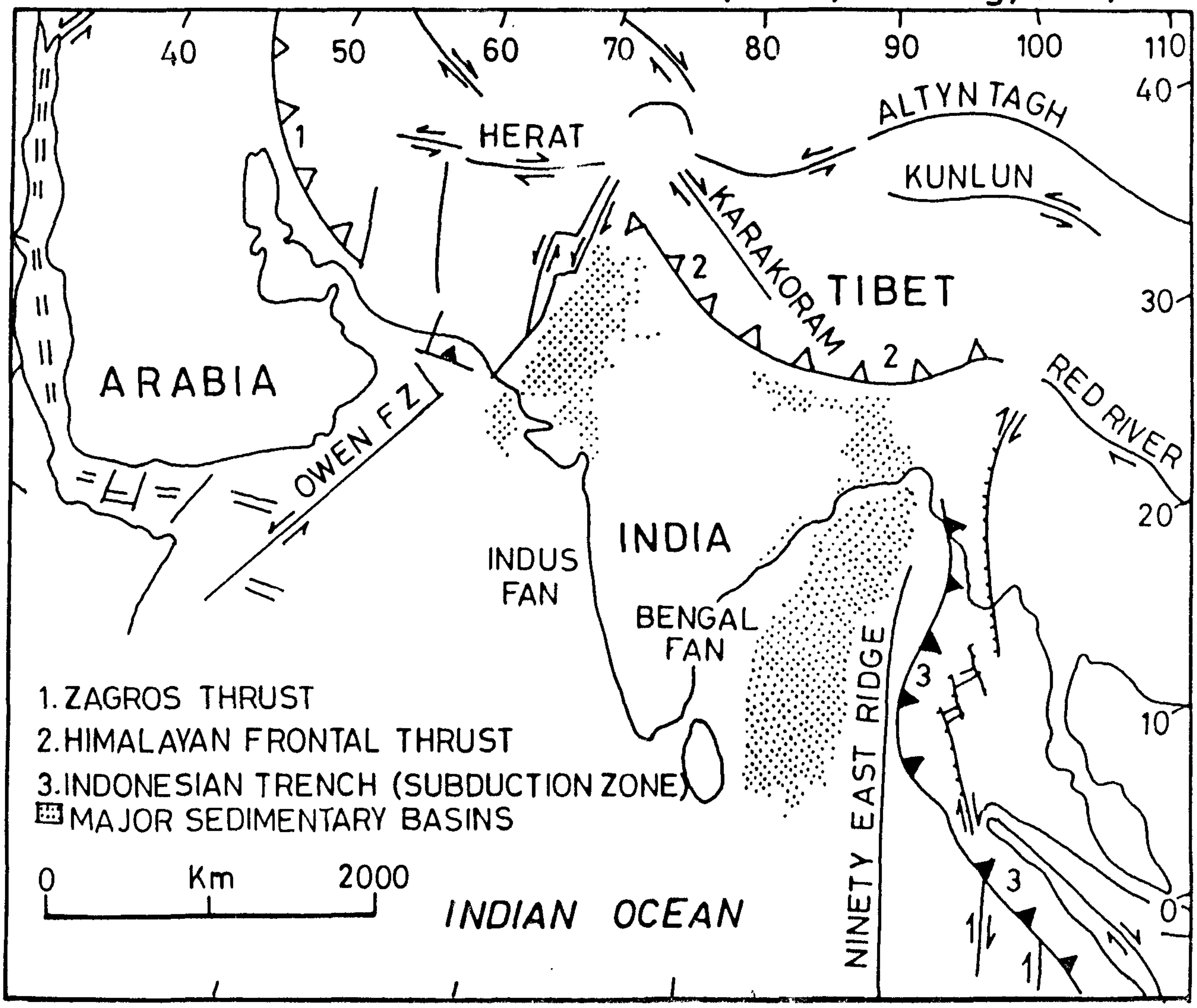
As regards the origin of the Ganga basin various shades of views are there, some of which are as follows.

It was interpreted to be a foredeep (Suess, 1904-1924) or a great rift valley (Burard, 1915), filled up with alluvium of thickness 4.5 km (Oldham, 1917) to 20 km (Pascoe, 1964).

According to Krishnan (1968) the Indo-Gangetic alluvial trough is a region whose origin and structure are closely connected with the formation of the Himalayas. He suggested that the Gangetic plains owe its origin to a sag or depression which has been formed by buckling down of the crust in obedience to pressure exerted on the borders of the Peninsula by compressive forces. Valdiya (1982) interpreted it as a resultant effect of sagging of the northern flank of platform around the Bundelkhand shield following the main episode of the Himalayas orogeny. The depressed platform became the site of sedimentation by vigorous fluvial agencies predominantly from the newly risen Himalayas.

FIG.12

MAP SHOWING CONTINENT–CONTINENT COLLISIO OF INDIA AND ARABIAN PLATES WITH ASIA (After, Reading,1986)



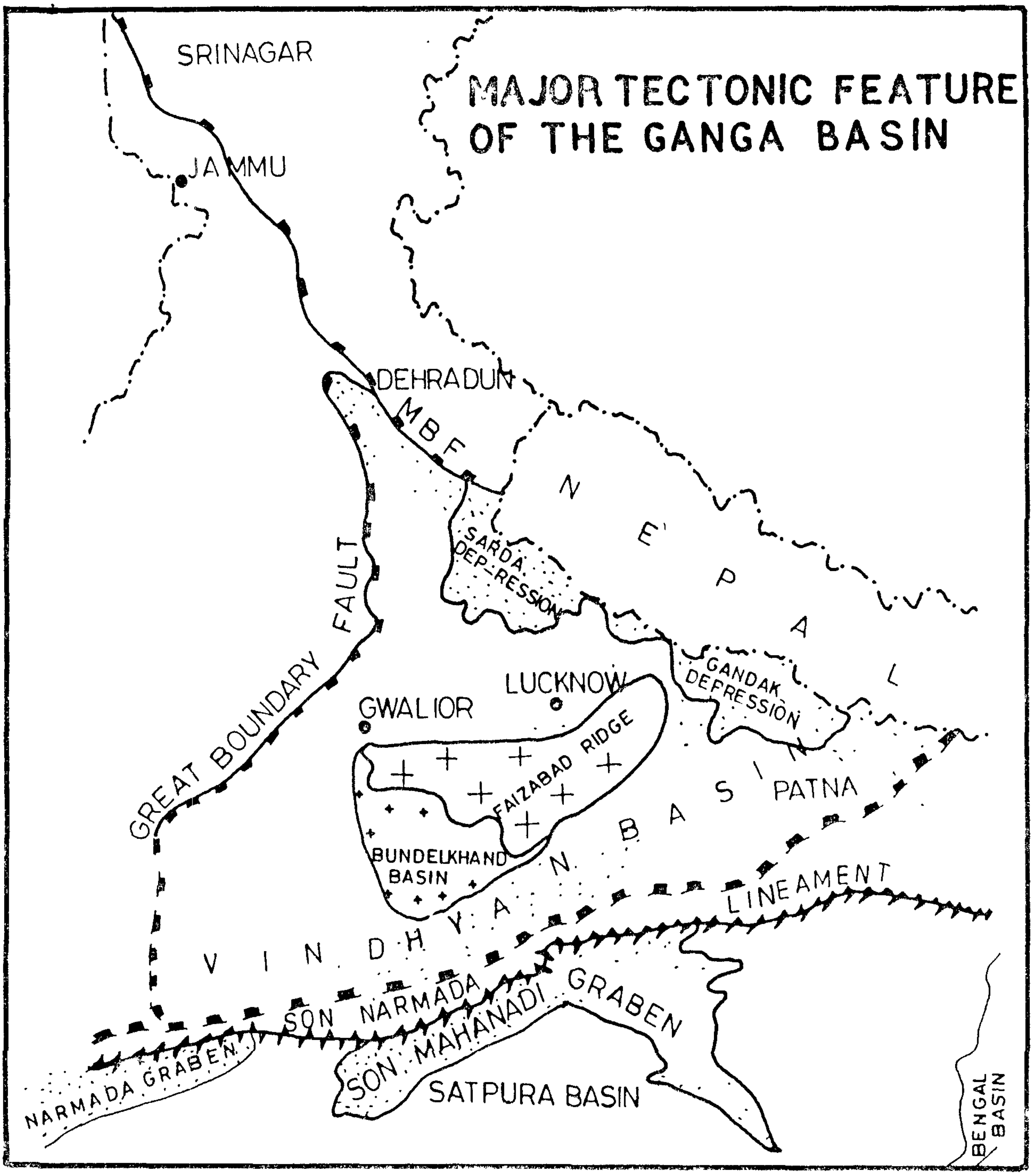
Canser (1964) has emphasized that the Ganga basin in front of the Himalayas does not represent a sediment filled foredeep but the depressed part of the peninsular shield which is in all likelihood, faulted against the outer Himalayan front.

According to Dickinson (1974) major sedimentary basins developed between fold-thrust belts and the craton, over which the mountain belt is thrust. "We call these basins fore-land basin, rather than fore deeps" (Miall, 1981; Bally, 1981). Fore-land basins are asymmetrical, and deepest near to the fold thrust belt; they migrate towards the fore-land and have resulted from down-ward flexturing of the lithosphere by over-riding fold thrust belt (Beaumount, 1981).

Dickinson (1974) considers the Indo-Gangetic trough as the most impressive. Present day peripheral fore-land basin (Figure 12) formed as result of continent-continent collison between Indian and Asian plates. The basin has developed on the under thrust Indian plate and due to loading of thrust sheets in Himalayas causing a viscoelastic flexture in the crust allowing sediments to accumulate under fluvial process.

According to Singh (1989) the Gangetic plain is part of active fore-land basin (peripheral-type) developed on the under thrusting Indian plate, in response to the thrust fold belt loading in the Himalayas. Further, Singh and Ghosh, (1988) and Singh (1989) opined that during thrust-fold loading tectonics in the Himalaya, the Son-Narmada lineament much to the south of the fore-land basin was

FIG. 13


MAJOR TECTONIC FEATURE
OF THE GANGA BASIN
SRINAGAR
JAMMU
DEHRADUN
MBF
NEPAL
SARDA DEP-RESSION
GREAT BOUNDARY FAULT
LUCKNOW
GWALIOR
GANDAK DEPRESSION
FAIZABAD RIDGE
PATNA
BUNDELKHAND BASIN
VINDHYAN BASIN
LINEAMENT
SON NARMADA
SON MAHANADI GRABEN
NARMADA GRABEN
SATPURA BASIN
BENGAL BASIN

reactivated, causing uplift of Bundelkhand-Vindhyan plateau and development of northerly slope (Fig. 13).

The rate of subsidence of the old, rigid and cold crust of Indian shield was also low and sediment input by rivers high, so that no marine transgression of Neogene-Quaternary time could enter into this fore-land basin. The deep drilling data of the O.N.G.C. is contrary to this view of Singh, as the deposits of Neogene sediments are reported from all over the Ganga basin (Sastri, 1971; Rao, 1973).

TECTONIC FRAMEWORK OF GANGA BASIN

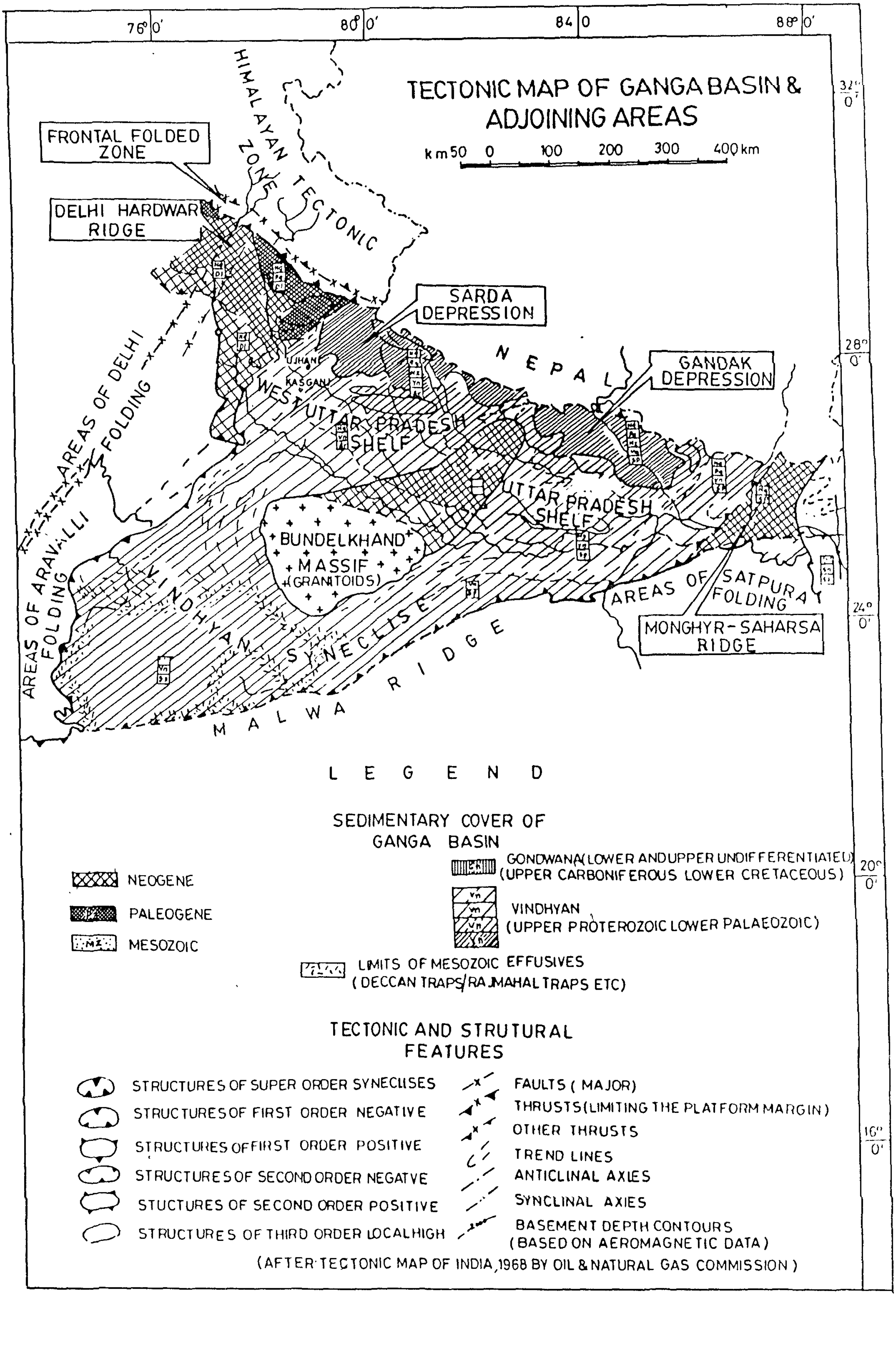
Tectonically the Ganga basin may be divided into the following sub-divisions (Fig. 14).

1. Monghyr-Saharsa Ridge
2. East Uttar Pradesh Shelf
3. Gandak Depression
4. Faizabad Ridge
5. West Uttar Pradesh Shelf
6. Kasganj-Tanakpur Spur
7. Ram-Ganga Depression
8. Delhi-Hardwar Ridge

1. Monghyr-Saharsa Ridge

It trends in northwest direction and denotes the sub-terranean continuation of Satpura orogenic belf of Chota-Nagpur

FIG.14


76° 0'
80° 0'
84 0
88° 0'
32° 0'
28° 0'
24° 0'
20° 0'
16° 0'
TECTONIC MAP OF GANGA BASIN & ADJOINING AREAS
km 50 0 100 200 300 400 km
HIMALAYAN TECTONIC ZONE
FRONTAL FOLDED ZONE
DELHI HARDWAR RIDGE
SARDA DEPRESSION
NEPAL
GANDAK DEPRESSION
UJHANI
KASGANJ
WEST UTTAR PRADESH SHELF
UTTAR PRADESH SHELF
AREAS OF DELHI FOLDING
AREAS OF ARAVALLI FOLDING
BUNDELKHAND MASSIF (GRANITOIDS)
VINDHYAN SYNECLISE
MALWA RIDGE
AREAS OF SATPURA FOLDING
MONGHYR-SAHARSA RIDGE
LEGEND
SEDIMENTARY COVER OF GANGA BASIN
NEOGENE
PALEOGENE
MESOZOIC
GONDWANA (LOWER AND UPPER UNDIFFERENTIATED) (UPPER CARBONIFEROUS LOWER CRETACEOUS)
VINDHYAN (UPPER PROTEROZOIC LOWER PALAEOZOIC)
LIMITS OF MESOZOIC EFFUSIVES (DECCAN TRAPS/RAJMAHAL TRAPS ETC)
TECTONIC AND STRUTURAL FEATURES
STRUCTURES OF SUPER ORDER SYNECLISES
STRUCTURES OF FIRST ORDER NEGATIVE
STRUCTURES OF FIRST ORDER POSITIVE
STRUCTURES OF SECOND ORDER NEGATVE
STUCTURES OF SECOND ORDER POSITIVE
STRUCTURES OF THIRD ORDER LOCAL HIGH
FAULTS (MAJOR)
THRUSTS (LIMITING THE PLATFORM MARGIN)
OTHER THRUSTS
TREND LINES
ANTICLINAL AXIES
SYNCLINAL AXIES
BASEMENT DEPTH CONTOURS (BASED ON AEROMAGNETIC DATA)
(AFTER TECTONIC MAP OF INDIA, 1968 BY OIL & NATURAL GAS COMMISSION)

Plateau. It marks the eastern bounding limit of the Ganga basin.

2. East Uttar Pradesh Shelf

It is delineated by Monghyr-Saharsa Ridge to the east and Faizabad Ridge to its west. The outcropping Vindhyan of Son valley and the granitic basement form the southern border of this zone. This shelf merges to the north into the Gandak depression. The basement here is assumed to be the continuation of the Bundelkhand massif, overlain successively by Vindhyan, Neogene and Quaternary alluvial sequences. A major north easterly trending fault, with a down throw to the southeast is traced from near Sahasram in south west through Muzaffarpur upto Nepal border. It is probably northward extension of Narmada-Son Lineament (Srivastava, 1983).

3. Gandak Depression

This depression is bounded to the west by Faizabad Ridge and to the east by Monghyr-Saharsa Ridge. Here the thickness of sediment is considered more than 6000 metres.

4. Faizabad Ridge

The Bundelkhand Massif occupies the central part of the Vindhyan Basin. The north eastern extension of this Massif in the sub-surface is known as the Faizabad ridge. This ridge has played a significant role during the deposition of the Vindhyan sediments (Fig.14).

Further the distribution of the Vindhyan sediments east and west of this ridge in the Ganga basin shows that the ridge has been a positive area throughout the sedimentation during the Vindhyans, dividing the basin into the eastern and western shelf (Srivastava et al., 1983). .

5. **West Uttar Pradesh Shelf**

The Western Uttar Pradesh shelf may be divided into two sub divisions, namely, the area to the east of the Moradabad fault and the area west of it. The eastern part of west Uttar Pradesh shelf which lies between Moradabad fault and western flank of Bundelkhand massif is one of the most well studied area of the Ganga basin. Not only the magnitude of ground-magnetic, gravity and detailed reflection and refraction siesmic surveys are more, but the area has been explored by two deep and four structural wells by the O.N.G.C. The drilling data show that the Upper Vindhyan directly overlies the Bundelkhand granite which is in turn overlain by Neogene sequences that is Siwaliks. Further, the upper Siwaliks is overlain by the Quaternary alluvium.

This west Uttar Pradesh shelf is traversed by the Great Boundary Fault which separates Aravallis from the Upper Vindhyans. This fault is a steep dipping reverse fault with a throw of 1500 m towards South-east, traceable for more than 500 kilometres from Chittorgarh to Agra with a NE-SW direction in the northern part, becoming almost N-S in the southern part, along the arcuate eastern flank of Aravalli folded belt (Fig. 15). The great Boundary fault continues north-eastwards and joins the Badaun Fault and further extends to Tanakpur close to the Himalayan foot hills.

The Moradabad Fault which also trends in NE-SW is considered to be an offshoot of the Great Boundary Fault.

Besides, these longitudinal faults various transverse faults of varying ages are also found to impress upon the stratigraphic sequences, some of these may be the resultant of the most violent third phase of the Himalayan orogeny. (Fig. 16).

In the western Uttar Pradesh Shelf, the basement and sedimentary cover of Upper Vindhyan and Neogenes, (Siwaliks), were cris-crossed by the longitudinal and transverse faults, generating thereby an uneven configuration of the sub-surface topography.

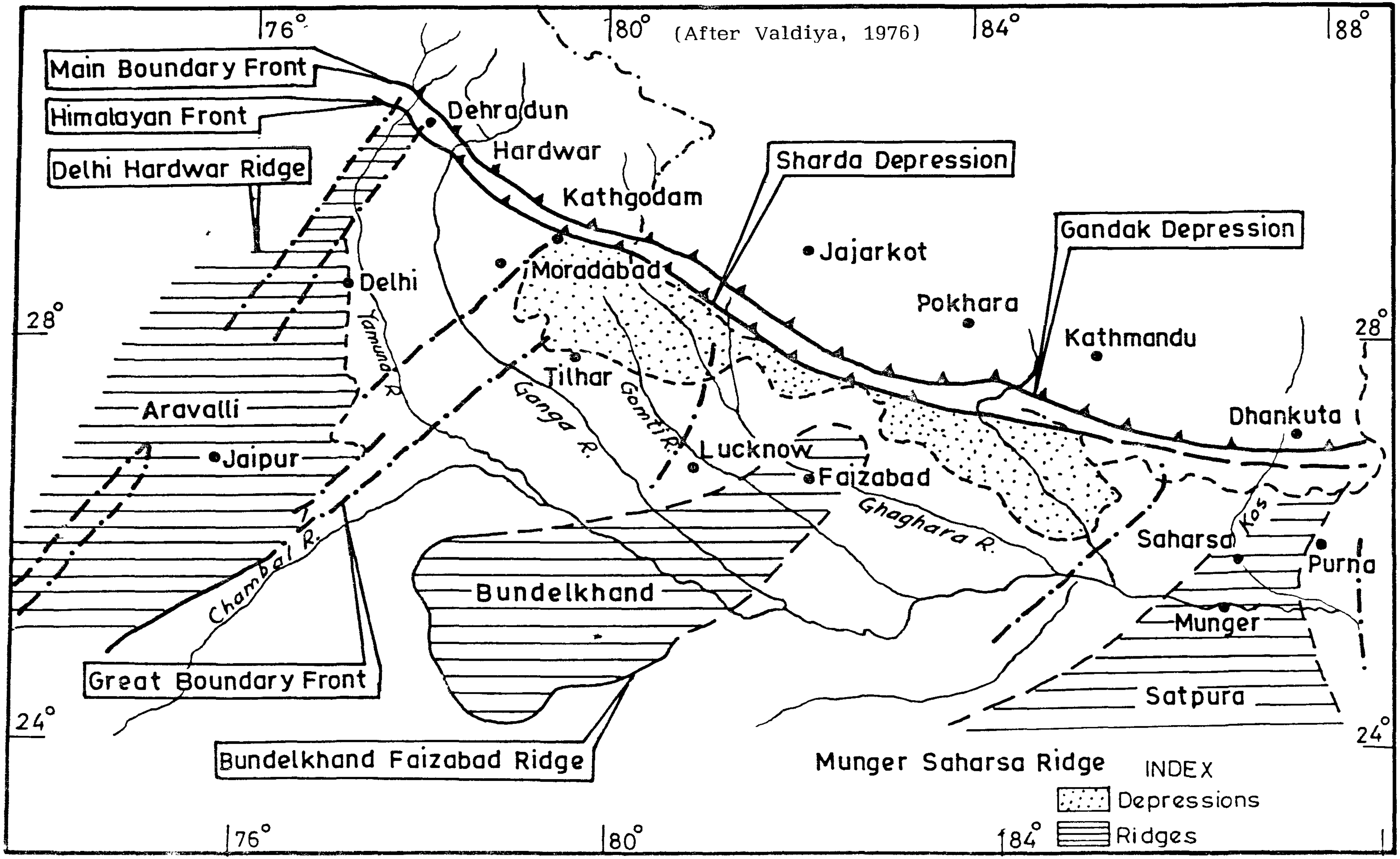
Sarda Depression

It represents the northern part of the west Uttar Pradesh shelf from which it is tectonically distinguished on the basis of inferred sedimentary thickness of more than 6000 m and by NW-SE trending structures. The large thickness of sediments in this depression may include partly the Mesozoic and Paleogene besides the Vindhyan Neogene and Quaternary Alluvium (Sastri et al., 1971).

THE STRUCTURE OF THE BASEMENT OF THE GANGA-BASIN

FIG.16

(After Valdiya, 1976)



Delhi-Hardwar Ridge

Represents a north-north-eastward extension of Delhi folded belt. The western limit of Ganga basin is probably delimited by Delhi-Hardwar Ridge and the oldest sedimentary sequence in the basin namely upper Vindhyans, gradually thin out towards this Ridge.

Kasganj-Tanakpur Spur

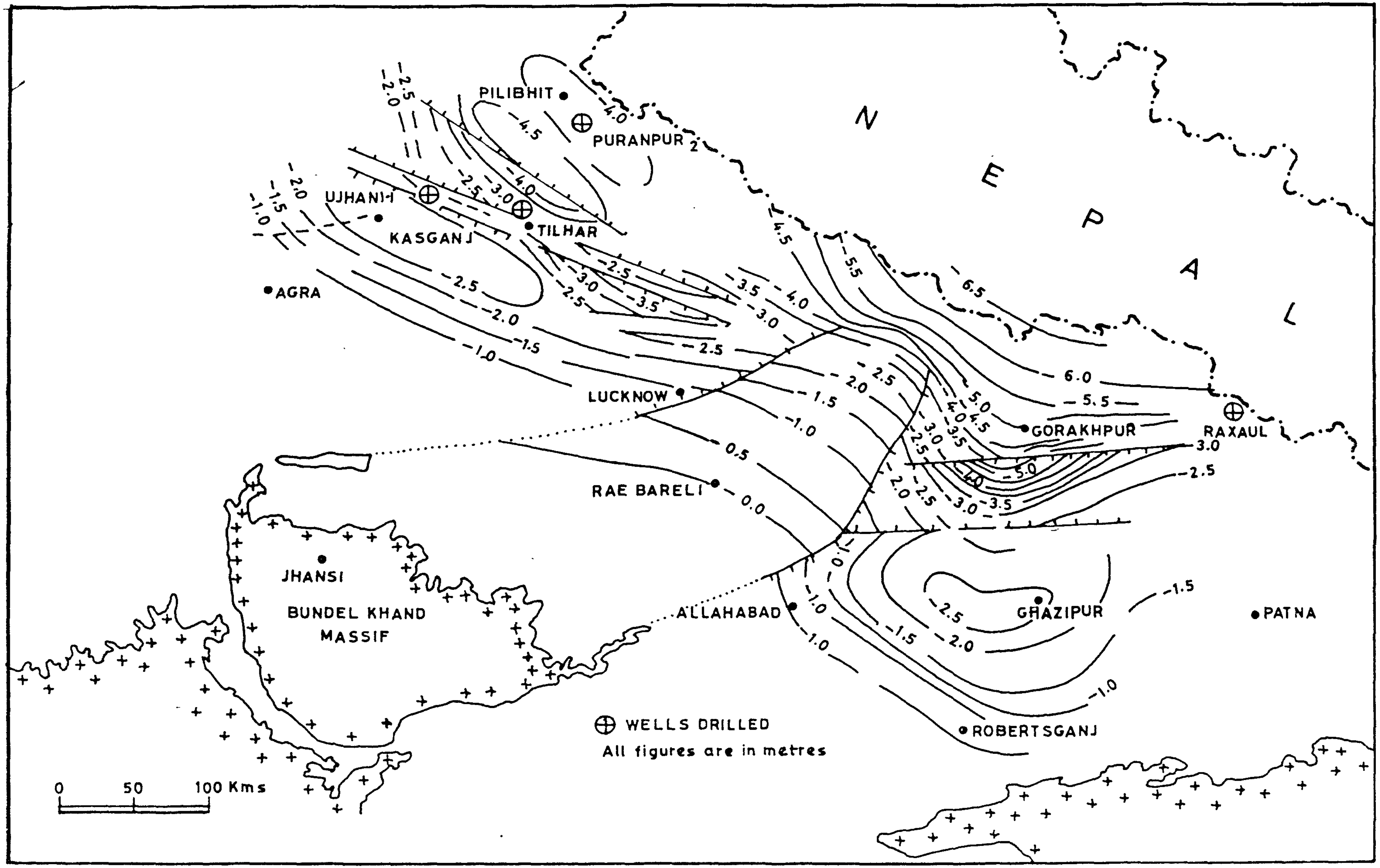
It is northern extension of the Badaun arch in the Ganga basin. This spur marks the eastern limit of Aravalli horst. Eastern edge of this spur coincides with the sub-surface extension of the Great Boundary fault (Raiverman et al. 1983) of Rajasthan which separates the Aravalli rocks from the Vidhyans (Fig. 16).

SUB-SURFACE GEOLOGY OF THE AREA

The study area lies on the Kasganj-Tanakpur spur, eastern edge of this spur coincides with the sub-surface extension of the Great Boundary Fault which separates the early Proterozoic Aravalli rocks from the upper proterozoic Vindhyan rocks in Rajasthan and beyond. The geophysical surveys by the O.N.G.C. have delineated an anticlinal structure below the unconformity (between the upper Vindhyan and overlying Siwaliks) at Kasganj and Ujhani (Fig. 17 & 18) under a cover of homoclinically dipping Siwaliks.

The tentative basement depth contour of the upper Vindhyans for the Ganga basin have been prepared from the available seismic

ISOPACH CONTOUR MAP OF THE VINDHYAN EQUIVALENT SEDIMENTS IN THE GANGA PLAINS
(After Hari Narain et. al 1982)
FIG.17



data by (Hari Narain et al., 1982). The map (Figure 18) in general, shows that the basement gradually slopes towards north and deepest part gradually lies close to the Himalayan foot hills. A large number of horst and graben structures within the Vindhyans have been mapped by seismic method which have been responsible for the abrupt variation in the thickness of Vindhyan sediments in the Ganga basin. Further, the sub-surface stratigraphic information obtained from deep and comparatively shallow structural wells drilled by the Oil and Natural Gas Commission in the Ganga basin has indicated the presence of Vindhyans below the Siwalik sediments. The geophysical and drilling investigation carried out by Oil and Natural Gas Commission, have yielded stratigraphic informations pertaining to the sub-surface geological framework which are as follows.

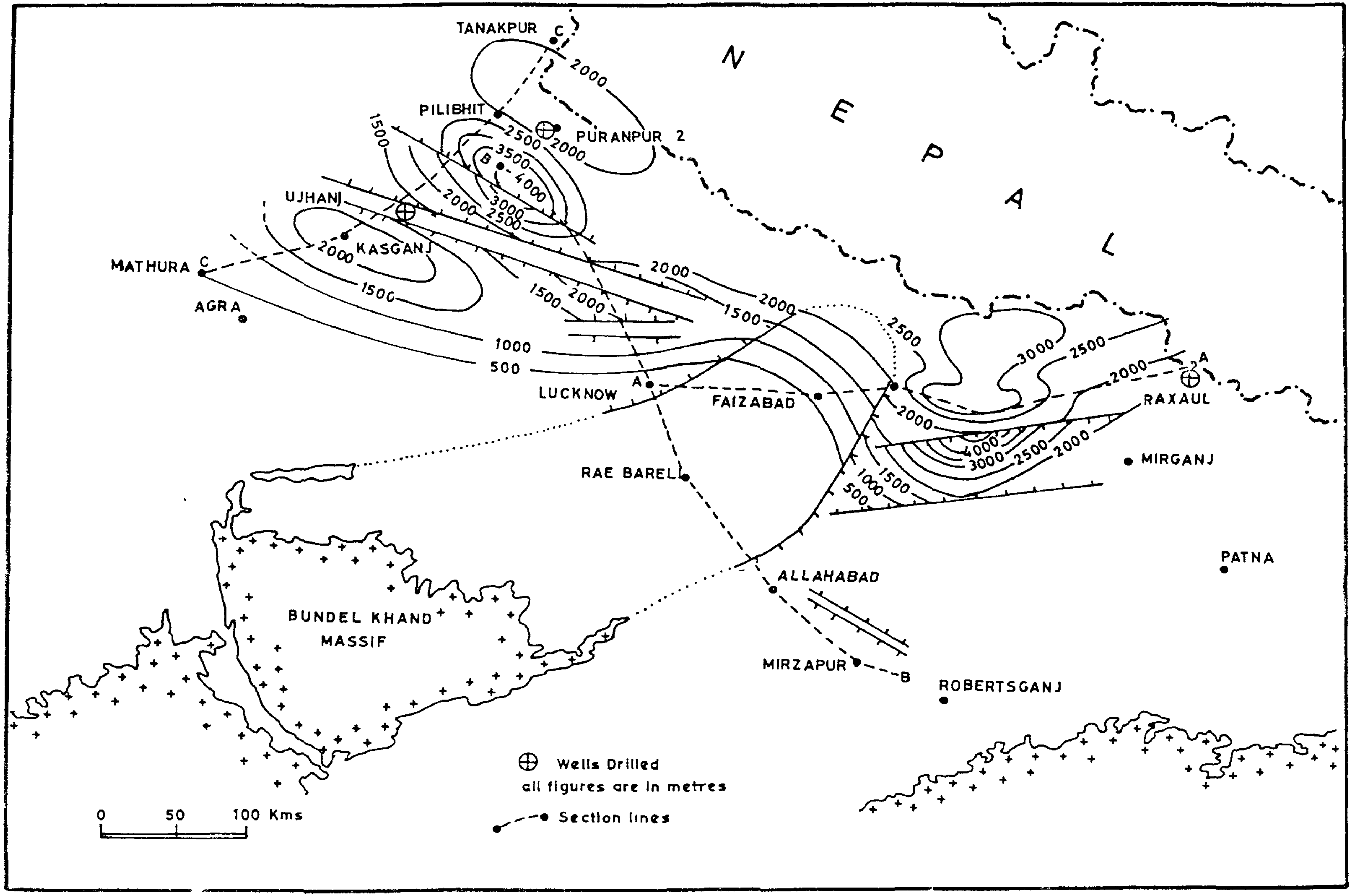
Table : Vindhyans in Ganga Basin

Wells	Depth interval (m)	Thickness	Age
Kasganj structural	620 - 1250	630	Upper Vindhyan
Ujhani deep well	1010 - 2062	1052	Upper Vindhyan
Tilhar	1718 - 2225	507	Upper Vindhyan
Puranpur	3174 - 4235	1061	Upper Vindhyan

TENTATIVE VINDHYAN BASEMENT DEPTH CONTOUR MAP FOR THE GANGA PLAINS

After Hari Narain et al.1982

FIG. 18



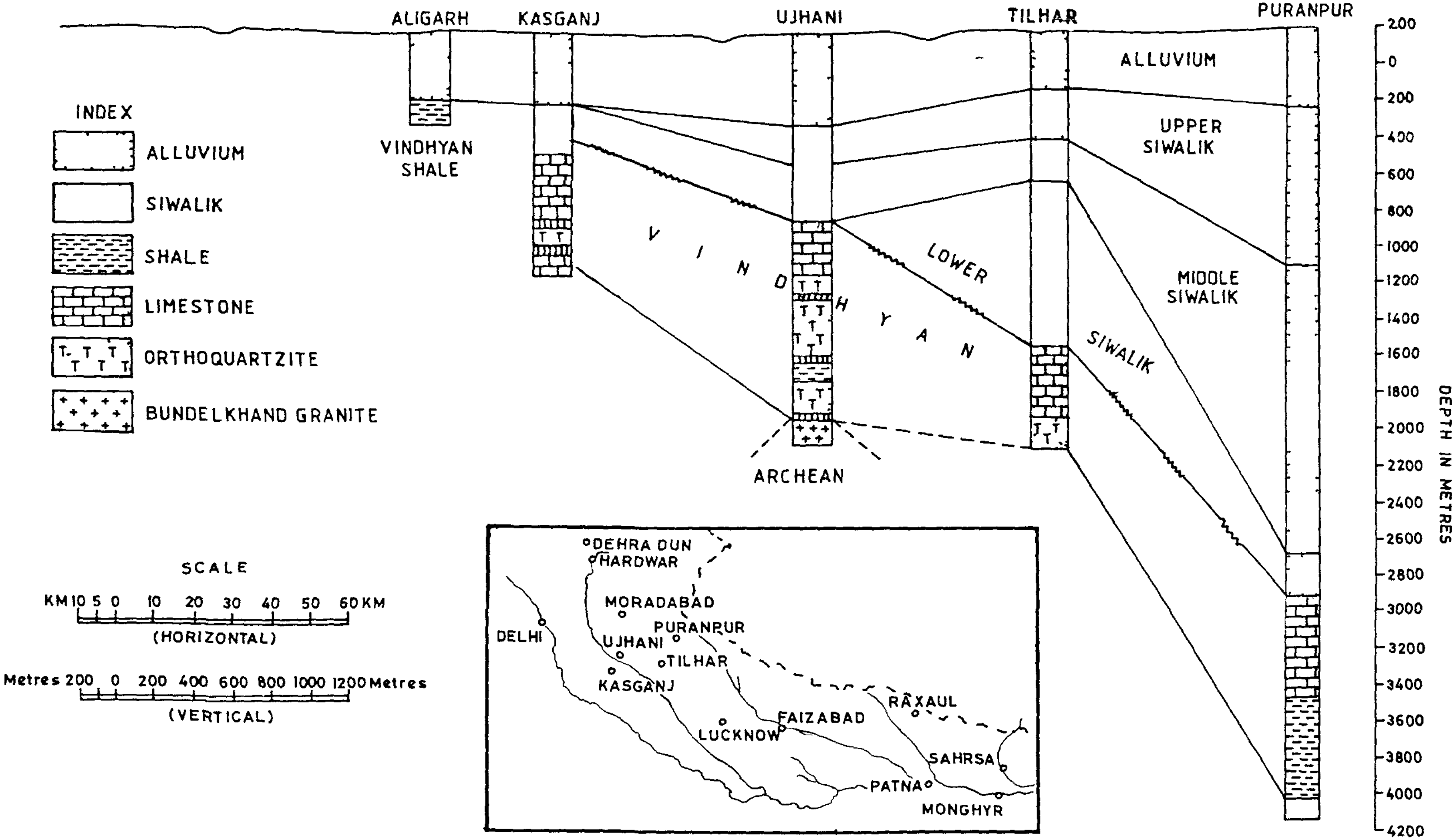
Based on the drilling data, sections were prepared and the stratigraphic correlation of the Vindhyan rocks and their equivalents in the Ganga basin are shown. (Fig. 19)

The figure shows that in Kasganj structural well the upper Vindhyan is encountered at a depth of 620 m which comprises limestone- sandstone-shale sequence with layers of anhydrite. The siwaliks (middle and upper) unconformably overlies the upper Vindhyan and attains a thickness of 260 m (620-360 m) which is in turn overlain by the Quaternary sediments (0-360 m). Further, in a deep well at Ujhani drilled down to the depth of 2062 m, the stratigraphic sequence of various geological formations are as under.

Sequence of Geological formations	Depth range (m)	Thickness	Age
Quaternary sediments	0 - 510	510	Quaternary
----------unconformity----------			
Siwaliks (Middle & Upper)	510 - 1018	508	Neogene
----------unconformity----------			
Upper Vindhyan	1018 - 2062	1052	Upper proterozoic
----------unconformity----------			
undelkhand ranitic basement	> 2062		Upper Archean

FIG 19

SUB-SURFACE GEOLOGICAL CROSS SECTION ALONG ALIGARH, KASGANJ, UJHANI AND PURANPUR IN PARTS OF CENTRAL GANGA BASIN



In Ujhani, the upper Vindhyan comprising Quartz-wacke Quarts-arenite, dolomitic limestone, shale and limestone from bottom upward, directly overlies the Granitic basement. The Siwaliks unconformably overlies the Vindhyan and is further overlain by the Quaternary sediments. Further, the Upper Vindhyan limestone-sandstone-shale sequence is the same at the Ujhani as was met in Kasganj structural well.

The upper Vindhyan attains a maximum thickness of 1052 m at Ujhani deep well, down to the basement. Further, the thickness of upper Vindhyans, Neogene Siwaliks and the Quaternary sediments gradually increases due north and perhaps attain their maximum thickness close to the Himalayan foot hills (Figure 19).

In the light of the above discussions the stratigraphic sequence of the various geological formations from Archean through upper Proterozoic to Quaternary are as follows.

Quaternary Alluvium	Alternate layers of sand and clay with interbeds of calc-concretions.

----------unconformity---------

Upper Siwaliks Middle Siwaliks (Neogenes)	Coarse to medium sandstone with variegated claystone and occasional carbonaceous streaks.

----------unconformity----------

Upper Vindhyan (Upper Proterozoic)	Greenish-greydolomitic Limestone Reddish-brown argillaceous Limestone. Quartz-wacke, Quartz-arenite.

----------unconformity---------

Archean	Bundelkhand granite basement

It appears from the above sequence that on the eroded surface of the basement, Upper Vindhyans were deposited sometimes during the upper Proterozoic era. Thereafter, they underwent Post-Vindhyan faulting and erosion since Cambrian to lower Miocene. During this long span of time encompassing about 500 M. years, the Vindhyan topography was reduced to almost peneplanations and on the eroded surface of upper Vindhyan the Siwaliks were deposited, which was followed by the deposition of Quaternary sediments.

This Quaternary deposits healed up all the earlier depressions through the rapid sedimentation giving thereby a broad, monotonous level expanses, which is the present Ganga basin.

There are in all, three unconformities. The first lies between the Bundelkhand granitic basements and the upper Vindhyan, the second between the upper Vindhyans and the Neogene Siwaliks and the third though indistinct lies between the Siwaliks and Quaternary deposits. The indistinct nature of the Siwaliks and the

Quaternary sediments are due to the broad lithological similarities. Moreover the velocity data obtained by the seismic survey do not make unconformity very distinct.

CHAPTER IV

HYDROGEOLOGY

The Ganga basin forms one of the most potential groundwater provinces of India (Pathak, 1978) of which the state of Uttar Pradesh forms an important part. The state of Uttar Pradesh has been divided into five hydrogeological units viz. Intermontane valley fills, Piedmont or Bhabar zone, Tarai zone, Central Ganga Plain and the Southern marginal plains (Fig. 20). These hydrogeological units form the great repository of ground-water and hold most potential aquifer in the state.

Intermontane Valley :

"Doon Valley" is the most prominent intermontane valley in the state which is a spindle shaped tectonic valley stretching along the central part of Dehradun District and bordered by lesser Himalayas in the north and the Siwalik ranges in the south. The valley is underlain by unconsolidated sediments comprising boulders, pebbles, cobbles and gravels of various sizes with intercalations of sands of various grades and little clay. Groundwater in the valley generally occurs under the water table and only at places under confined conditions. The static water level in the tubewells ranges from 22 meters to 76 meters below the land surface and discharges 180 m^3/hour for draw down varying from .07 to 8.4 metres.

Bhabar :

The Bhabar belt stretches parallel to the Himalayan foot hills due south upto the spring line. The general width of belt ranges from 10 to 30 kms. The Bhabar belt is composed of Peidmont deposits formed by lateral coalesence of fan deposits of innumerable streams emerging out of the Himalayas. Lithologically it comprises, boulder, cobbles pebbles and gravels mixed with sand. Groundwater in these deposits is mostly unconfined and water table is generally deep being 30 metres or more below land surface. Perched water bodies are of common occurrence.

The tubewells yield varies between 97 to 227 m^3/hours for draw down varying between 2.7 and 9.7 metres. The hydraulic conductivity ranged between 15-250 m/day.

Tarai or Wet Land Zone :

The deep water table at the foot hills cuts the land surface and gives rise to the series of springs hence this zone is called as wet land zone or Tarai zone. The spring line defines the northern limit of Tarai, while its southern limit imperceptibly merges with the central Ganga plain. This is about 8 to 16 kms. wide and runs parallel to Bhabar zone. The belt is characterised by predominent clayey sediments with intercalated beds of sands and gravels with frequent free flowing conditions. The piezometric head in the following wells of this zone varied between 6.60 and 8.90 metres above the ground level.

Central Ganga Plain :

Southern limit of the Central Ganga plain is fixed by Yamuna and its confluence with Ganga stretching from west-north-west to east-south-east, this sub-zone covers major part of the state encompassing the Ganga-Yamuna interfluves and contain several potential aquifers down to the bed rocks. The Quaternary alluvium consists of gravels and sands of various grades, silt, clay often intercalated with calcareous concretions in varying portions. The aquifers are generally lenticular in nature and there are rapid alternations and gradations between granular and clayey horizons. The near surface groundwater occurs under unconfined while deeper aquifers generally contain water under semi-confined to confined conditions.

Marginal Alluvial Plain:

This sub-zone lies between central Ganga Plain and the region occupied by Bundelkhand granite and the Vindhyan group of rocks. Alluvium with its limited thickness is composed of clay mixed calcareous concretions, silt and sands of various grades with occasional gravel. Groundwater in this belt occurs under unconfined to confined conditions. The Piezometric surface in the tubewells generally ranges from flowing conditions to 26 metres below ground level. The discharge of tubewells varies between 60 to 240 m^3/hour for drawdown from 3 to 16 metres. The tract holds promise for groundwater development on moderate scale. The study area i.e. Ganga-Kali sub-basin is a part of Ganga-Yamuna interfluves which forms a part of the Central Ganga plain.

The river Ganga which is the principal stream of the Ganga basin has given rise to various aquifer types through its varying flow regimes during the 0.6 Ma.

EVOLUTION OF AQUIFERS :

The evolution of aquifers in fluvial system is dependent upon the hydrodynamics of the flow regime, geology and topography of the terrain, leading to the terrigenous clastic deposition system, which are typically represented as the channel, flood plain, and back swamp deposits.

Channel Deposit :

The typical channel deposits of the river Ganga as observed in the study area from bottom upward comprise coarse sand mixed with gravel through medium to fine sand to silt and finally capped by a thin clay layer at the top. This top clay and some fine sand layers are washed away during the succeeding flood period and a fresh body of sand with the fining upward sequence is deposited again each year during the flood, forming thereby a reasonably thick terrigenous clastic deposits till the river changes its course due to some tectonic control through convulsion.

These thick bodies of sand form the potential repositories of ground water or the most potential aquifers.

Flood Plain Deposit :

During the flood season when the flood water overflows the banks, medium to fine sand bodies of moderate thickness and limited areal extent are deposited over the flood plain. These lenticular bodies of sand form the moderately potential aquifers in comparison to the highly potential aquifers of the channel deposits.

Back-Swamp Deposit or Oxbow Lake Deposit :

The flood water, further moves down the slope, to the low lying areas where it is left predominantly with the suspended materials which get settled under the influence of gravity and form a lensoid body of sand which is further overlain by the still finer clastics i.e. clay. Thus there occurs enclaves of sand bodies intercalated within the underlying and over-lying thick clay beds. Such bodies of sand form the low potential aquifers. These aquifers are typical representatives of back swamp environment or Oxbow Lake environment.

Thereafter, the river changes its course under tectonic control through convulsion or some other factor like earthquake etc. Thus with the passage of time, the position of channel, flood plain,

FIG 21

MAP SHOWING THE AREA SURVEYED WELLS AND TUBEWELLS INVENTORIED IN GANGA-KALI SUB-BASINS and back swamp deposits also continue changing. That is why we do not get continuous body of sand or clay except under certain extraordinary situation in a single drill hole. The above lithological variations are attributable to their mode of deposition by the constantly shifting nature of the river Ganga.

The Ganga fluvial system which has generated various aquifers in the area are as under:-

a) The channel deposits are thick bodies of aquifers of infinite areal extent, hence form most potential ground water reservoir.

b) Flood plain deposits giving rise to the lenticular type of aquifers, limited in thickness and areal extent and are only moderately potential.

c) Lensoid bodies of sand occurring as enclaves or stringers within the thick clay bed, generally form the low potential aquifers often with the quality problems.

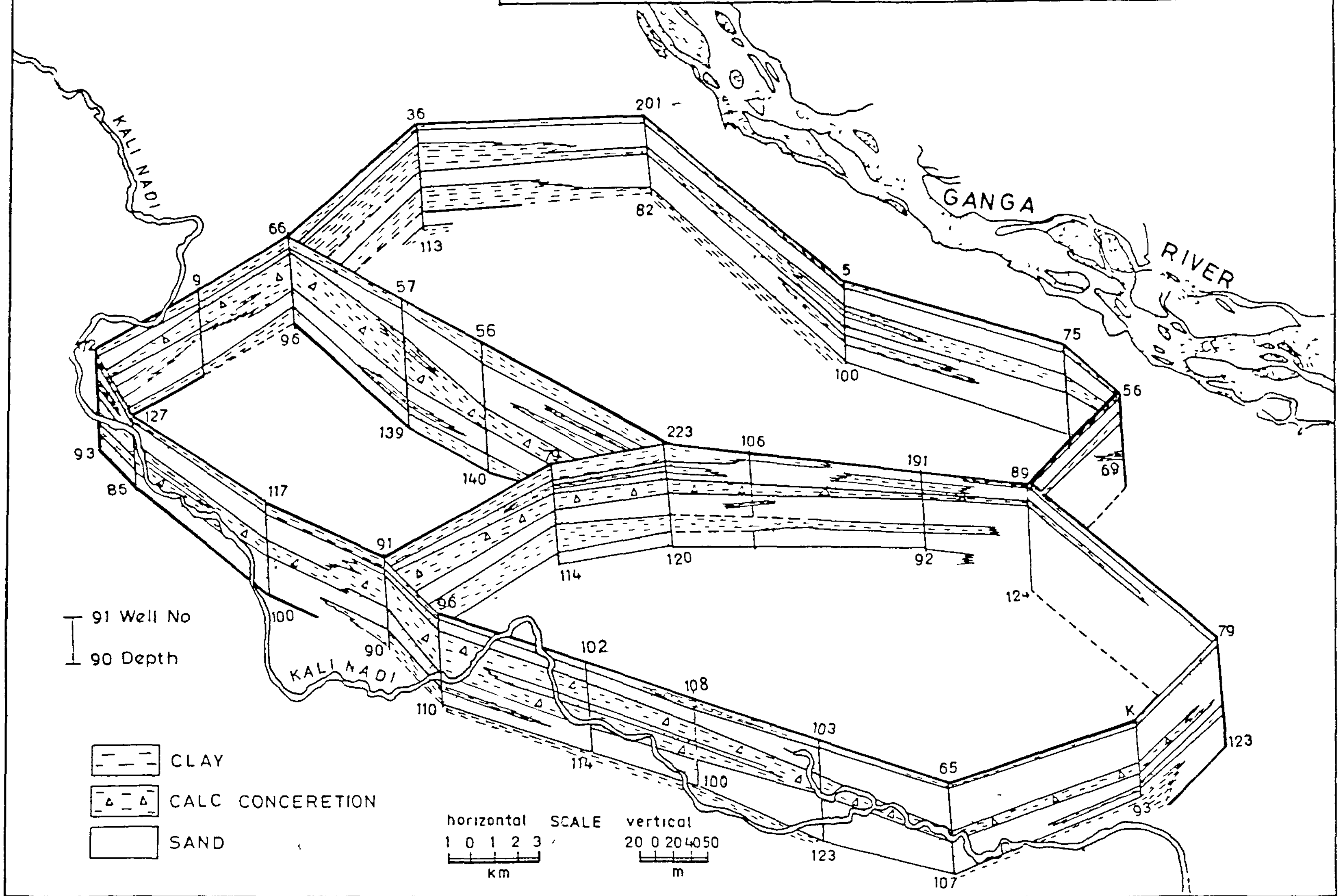
We find that in a thick Ganga alluvium, the complexes of the channel, flood plain, and back swamp facies reappear several times in a well drilled at places in the area. Thus the terrigenous clastic depositional system of the river Ganga in the area of study is an index of its complex hydrodynamic regime which generated various aquifer in great Ganga plain.

Aquifer Geometry :

A fence diagram (Fig. 22) based on the lithological logs of the boreholes drilled by the State Tubewell Department has been

FIG 22

FENCE DIAGRAM SHOWING AQUIFER SYSTEM IN GANGA-KALI SUB BASIN IN ALIGARH AND ETAH DISTRICTS



prepared. Besides it, five hydrogeological cross-sections were also prepared along line A-B, C-D, E-F, G-H, and I-J (Fig. 23). The location of these lines are shown in Fig. 21 .

The fence diagram reveals the vertical and lateral disposition of aquifers, aquiclude and aquitard in the study area down the depth of 150 metre b.g.l. A perusal of fence diagram shows that in all there occurs two to three-tier aquifer system down to the depth of 150 m.b.g.l.

By and large these aquifers appear to merge with each other and behave as a single bodied aquifer system. Further, the granular zones comprising medium to fine grey micaceous sand, occasionally mixed with coarse sand and gravel form about 80 to 90% of total formations encountered, particularly in the eastern part proximal to the Ganga river. There, the granular zones attain maximum thickness and appears to be the channel deposit of the river Ganga. It is also confirmed by the section G-H which shows that the clay beds occur simply as a lensoid body.

From east to west direction the clay beds gradually start attaining thickness and occur in repeated alternation with the granular zones. The percentage of granular zone is around 50 to 60% and it appears to be the flood plain deposit. It is substantiated by the section A-B which shows alternate sand and clay beds where the clayey horizons gradually pinch out due east. Similar position is observed in the central part of the area too.

FIG. 23-a

HYDROGEOLOGICAL CROSS-SECTION ALONG A – B

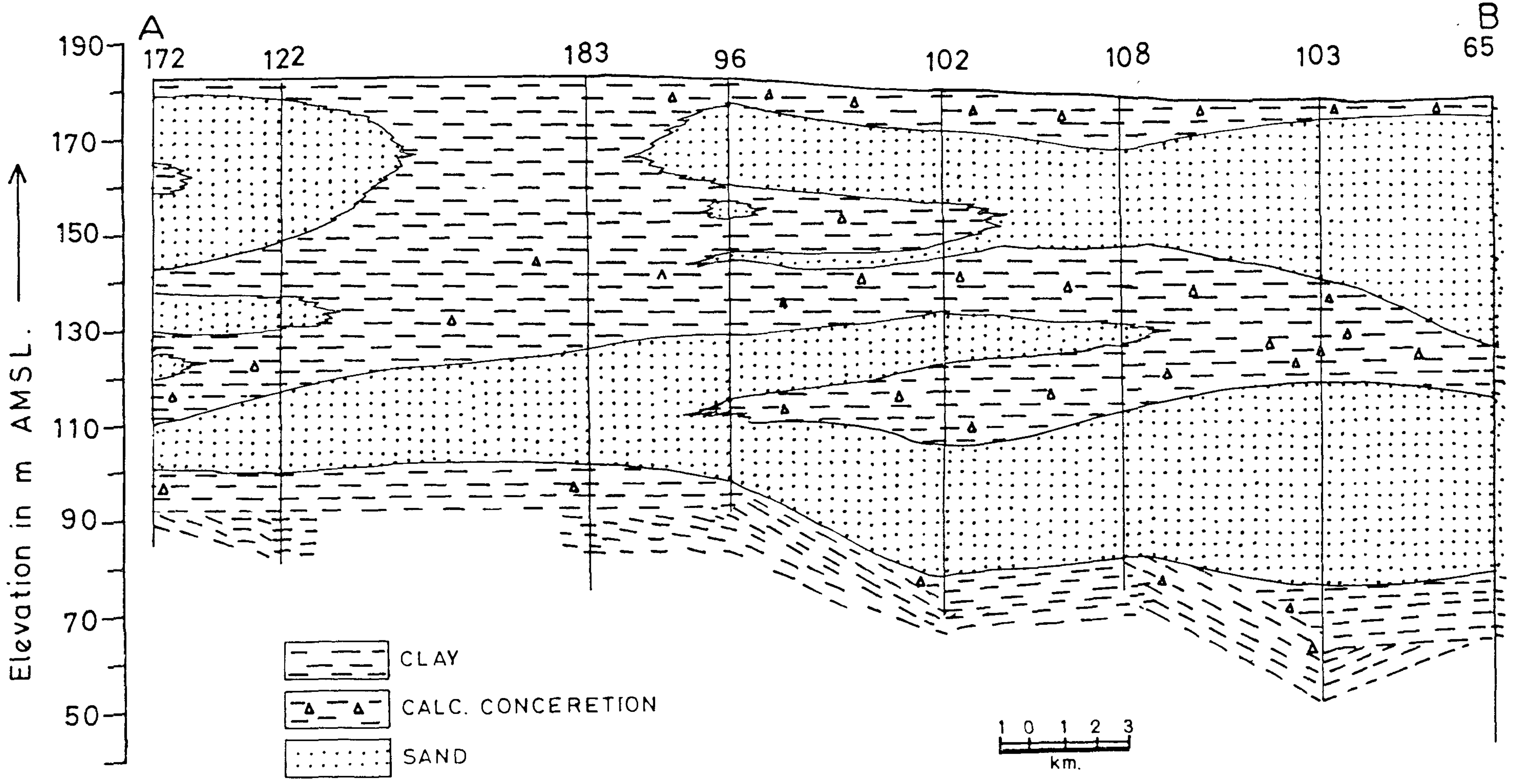


FIG. 23-b

HYDROGEOLOGICAL CROSS SECTION ALONG C-D

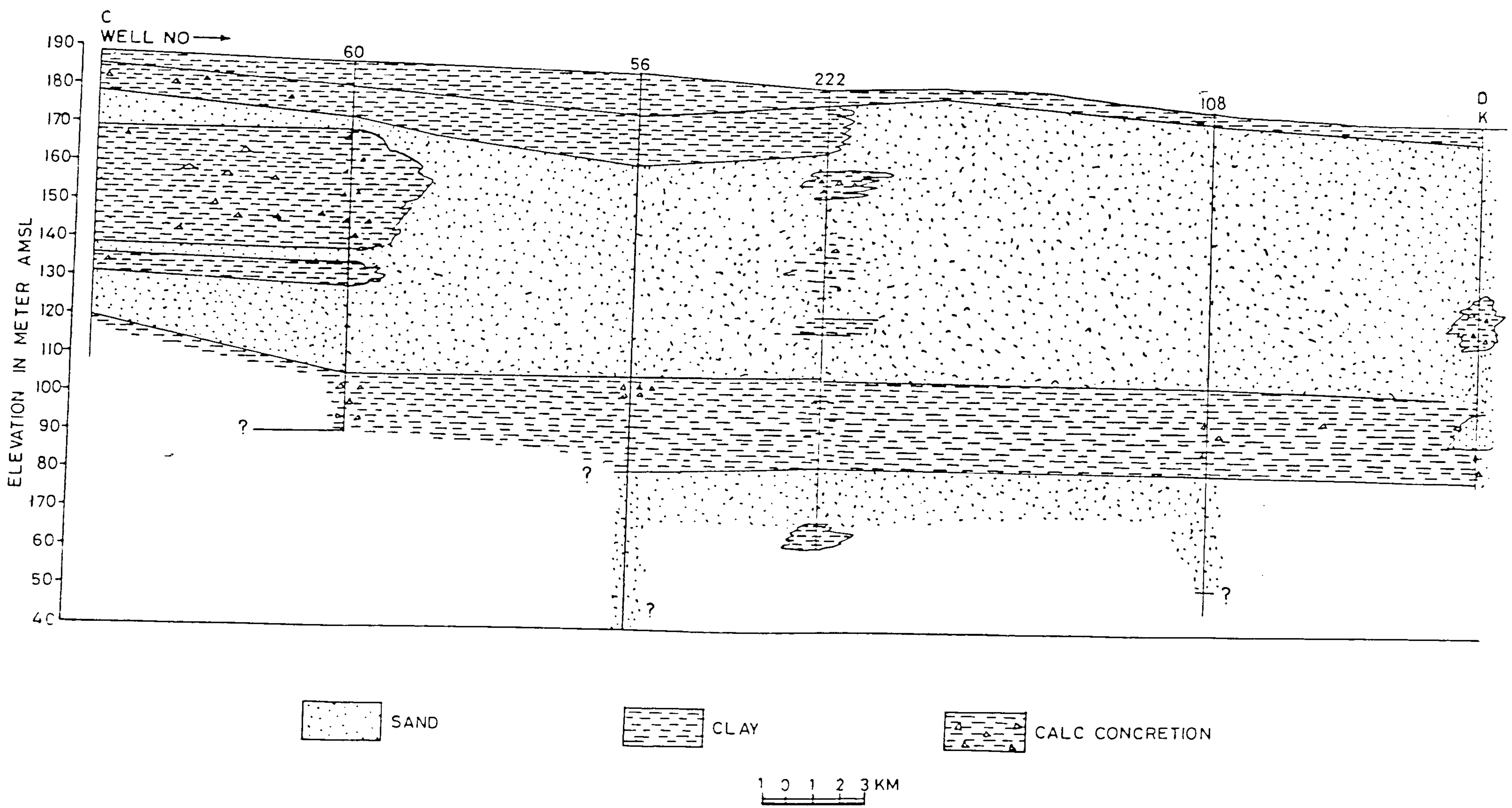
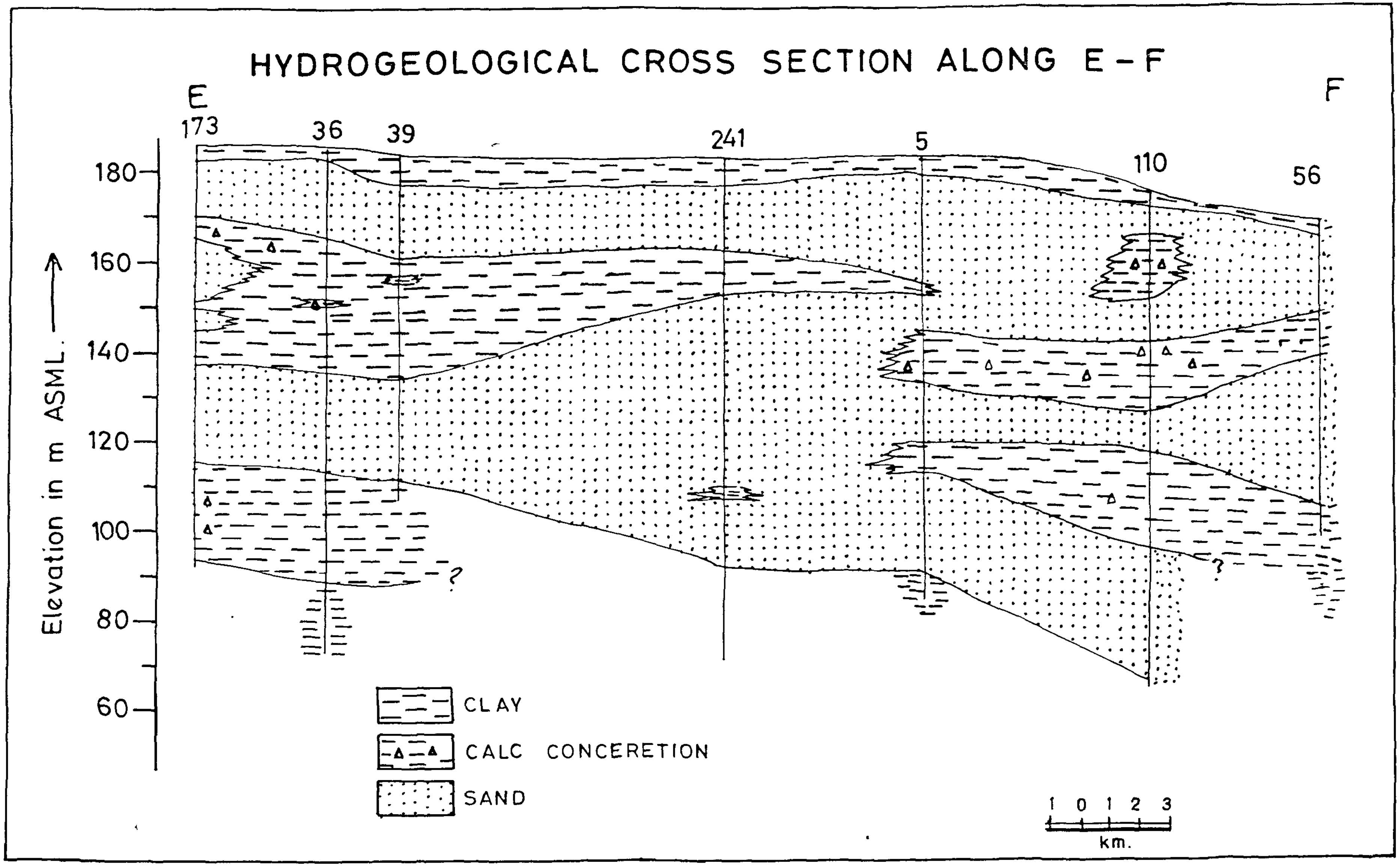


FIG. 23-C



HYDROGEOLOGICAL CROSS SECTION ALONG E-F
E
F
173
36
39
241
5
110
56
Elevation in m ASML.
180
160
140
120
100
80
60
?
?
CLAY
CALC CONCERETION
SAND
1 0 1 2 3
km.

FIG. 23-d

HYDROGEOLOGICAL CROSS SECTION ALONG G-H

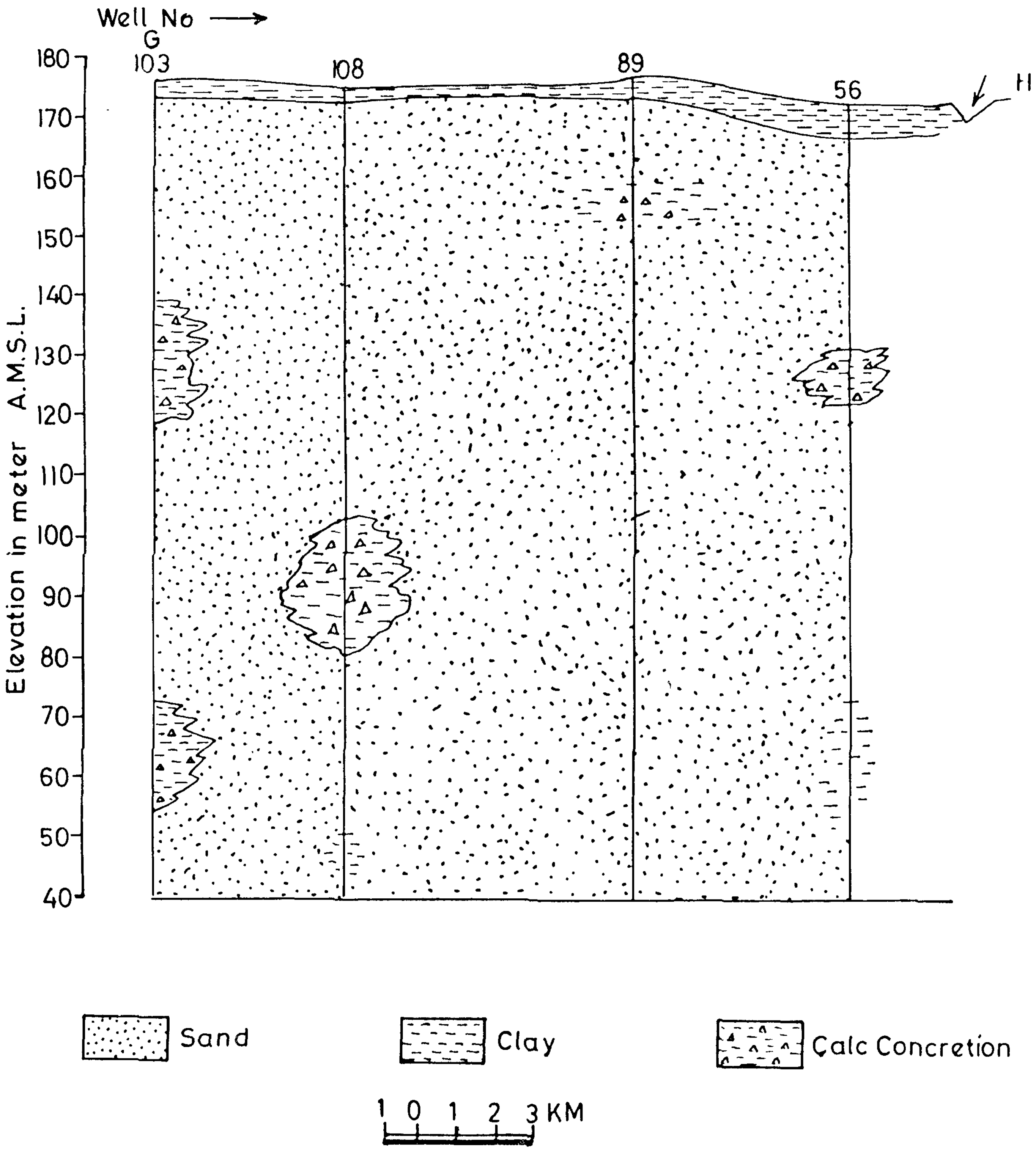
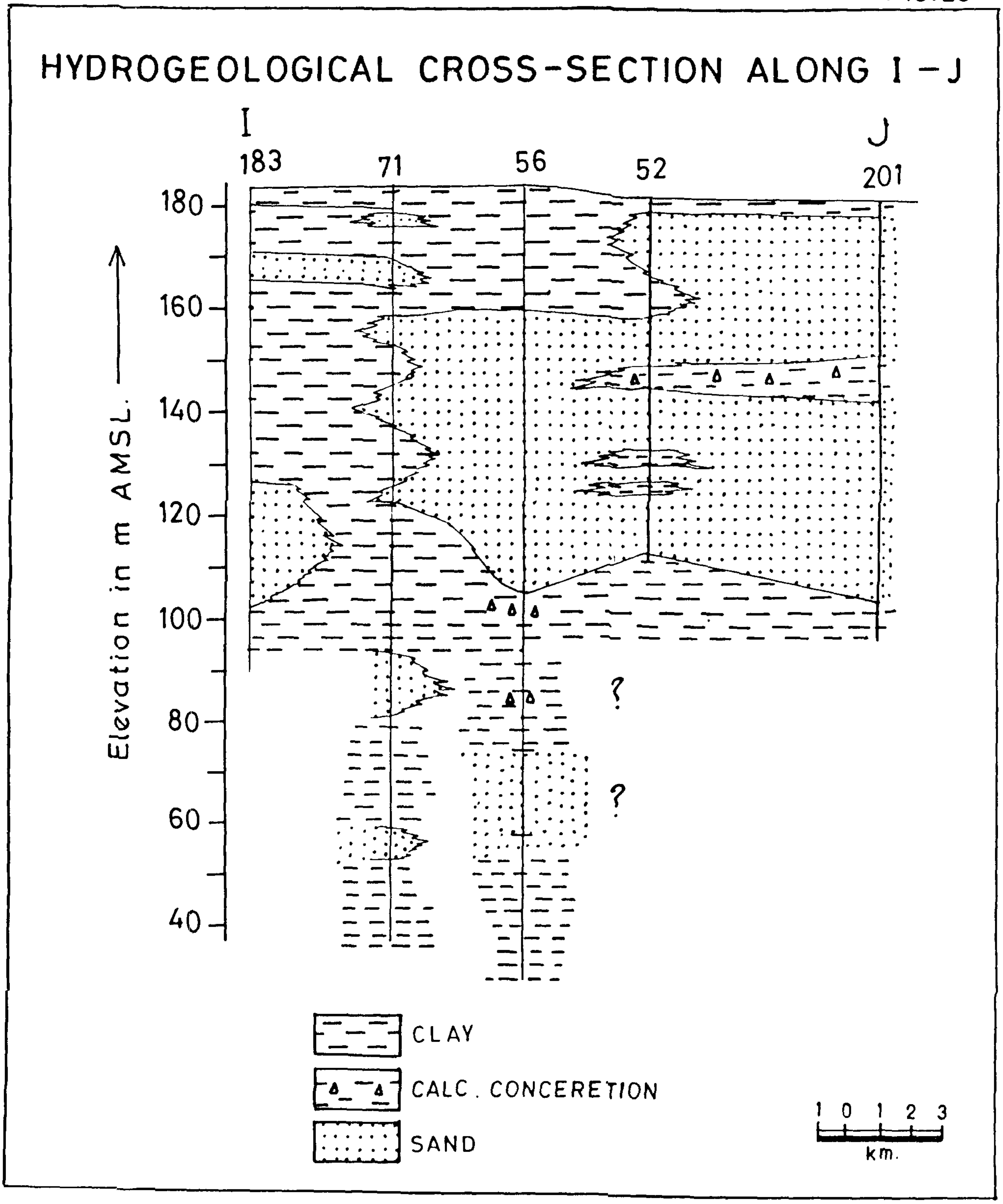


FIG. 23

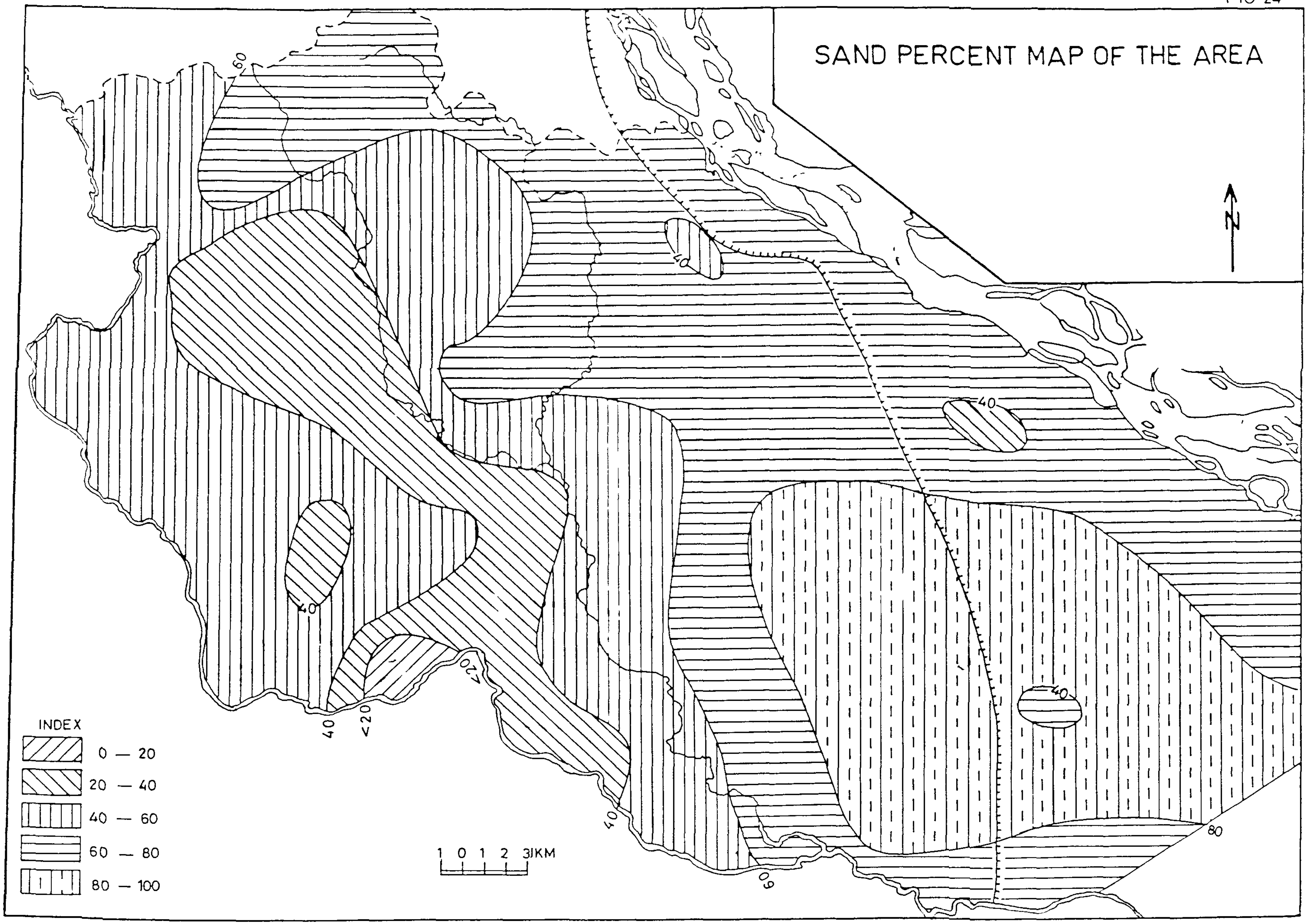

HYDROGEOLOGICAL CROSS-SECTION ALONG I - J
I
J
183
71
56
52
201
Elevation in m AMSL.
180
160
140
120
100
80
60
40
?
?
CLAY
CALC. CONCERETION
SAND
1 0 1 2 3
km.

The most peculiar sub-surface hydrogeological set up is found in the western parts of the area close to the river Kali, where the clay predominates over the sand. The aquifer zones occur as lenticular bodies of sand intercalated within the thick beds of clay. The granular zone here comprise 30 to 40% of total lithounits. These appear most probably as back swamp deposits.

Sand Percent Map

Sand percent map (Fig. 24) for the aquifer materials encountered down to the depth of 70 metres has been prepared to identify their thickness and lateral extents. For the purpose, the area has been divided into five sand percent zones viz. <20 (2) 20-40 (3) 40-60 (4) 60-80 (5) >80 percent. The value of sand percent varies from place to place in the area, the zone proximal to the Ganga river shows the granular formations ranging between 60 to 80% of the total lithological contents. West of the Ganga river in the upland lying between Lower Ganga canal and Nim river, the zone shows abnormally high percentage (>80%) of granular materials (Fig. 24). Further, in the area lying between the Nim and Kali rivers the percentage of sand decreases gradually due west, which touches the lowest (< 20%), a place at Pusawali close to the left bank of the Kali river. Moreover, there is also a stretch of land occuring along the banks of chhoiya river extending upto Atrauli village, where the percentage of the granular zones ranges between 20-40%.

FIG 24


SAND PERCENT MAP OF THE AREA
N
INDEX
0 — 20
20 — 40
40 — 60
60 — 80
80 — 100
1 0 1 2 3 KM
60
40
40
40
40
<20
<20
40
40
60
80

However, there are few more places where the percentage of the granular zones ranges between 30 to 40% of total lithological units encountered down to the depth of 70 metres.

The sand percent map reveals that the granular zones attain a maximum thickness of >80% in the tract lying between the Lower Ganga canal and Nim river, which further extends due south towards Kasganj. The percentage of the granular material, in general, decreases gradually due west and touches less than 20% marks vis-a-vis clayey formations proximal to the left bank of the Kali river. This is further substantiated by the fence diagram and through the various hydrogeological cross-sections (Fig. 22 & 23).

Fine through medium to coarse sand generally comprise the aquifer material in the area.

Grain Size Analysis of the Aquifer Materials

Particle size of the Gangetic alluvial deposits is an important textural element as it is related to the hydrodynamic conditions of deposition of the Ganga river system.

The most common method of measuring particle size is sieving. The process of analysing sediments for the range sizes present, is called mechanical analysis. The purpose of mechanical analysis is to obtain graphic or numerical data about particle size in a sediment. Size analysis has been used in determining if a sand will contain water.

The economic development and utilization of groundwater resources require an understanding of the factors that govern hydraulic transmission of groundwater through an aquifer. One of the most important quantitative measure of such transmission is the permeability which may be considered as the ease with which water flows through a porous medium, and is dependent both upon physical properties of the flowing water and characteristics of transmitting medium. In many natural occurrences the lower the physical properties of flowing water, i.e. viscosity and specific weight are practically constant so the permeability may be considered to be a function of the properties of medium alone (Masch, 1966). Such medium properties include the particle size, shape, structure, degree of compaction and grain size distribution.

Many earlier workers attempted to relate properties of aquifer materials to the transmitting capabilities of an aquifer.

Krumbein and Monk (1942) studied the effect of both particle size and sorting in artificially mixed sand and expressed their results in following semiempirical equation.

$$K = 760\ d^2\ e^{-1.36\sigma}$$

where K is permeability in darcys

d = geometric mean diameter

e = dimensionless constant 2.718

σ = the log standard deviation of size distribution which is dimensionless and 760 is a constant for the conversion of permeability units to Darcy.

A correlation between the laboratory permeability values and median grain size was developed by Bedinger (1961). He found that straight line relation existed between the logarithm of the permeability and the median grain size diameter. The result of this work revealed that the permeability expressed in gal/ft^2/day ranged from 9000 for very coarse sands to about 10 for very fine sands. Jhonson (1963) has done experimental work similar to Bedinger, his results also were found in very close agreement with those of Bedinger.

Prouss and Todd (1963) attempted to relate the specific yield to several physical properties of sedimentary samples including representative grain size diameter and a uniformity coefficient they found that d_{50} or median grain size was best studied as a measure of representative grain diameter. The uniformity coefficient used to describe the sample was defined as follows.

$$U = d_{60}/d_{10}$$

The result of this study indicated maximum value of specific yield occurred for d_{50} between 0.4 to 0.5 mm and the specific yield decreased for the values of d_{50} out side this range. They also concluded that in general specific yield decreased as the magnitude of uniformity coefficient increased. Studies by Cohen

(1963) resulted in findings similar to those Preuss and Todd.

Masch, (1966) concluded that permeability values increase with increasing value of the Md_{50} diameter.

Uma et al., (1989) has given a new statistical grain size method for evaluating the hydraulic conductivity of sandy aquifers which is as follows

$$K = A\, d_{10}^2$$

where,

K = hydraulic conductivity

A = constant

d_{10} = *effective grain size.*

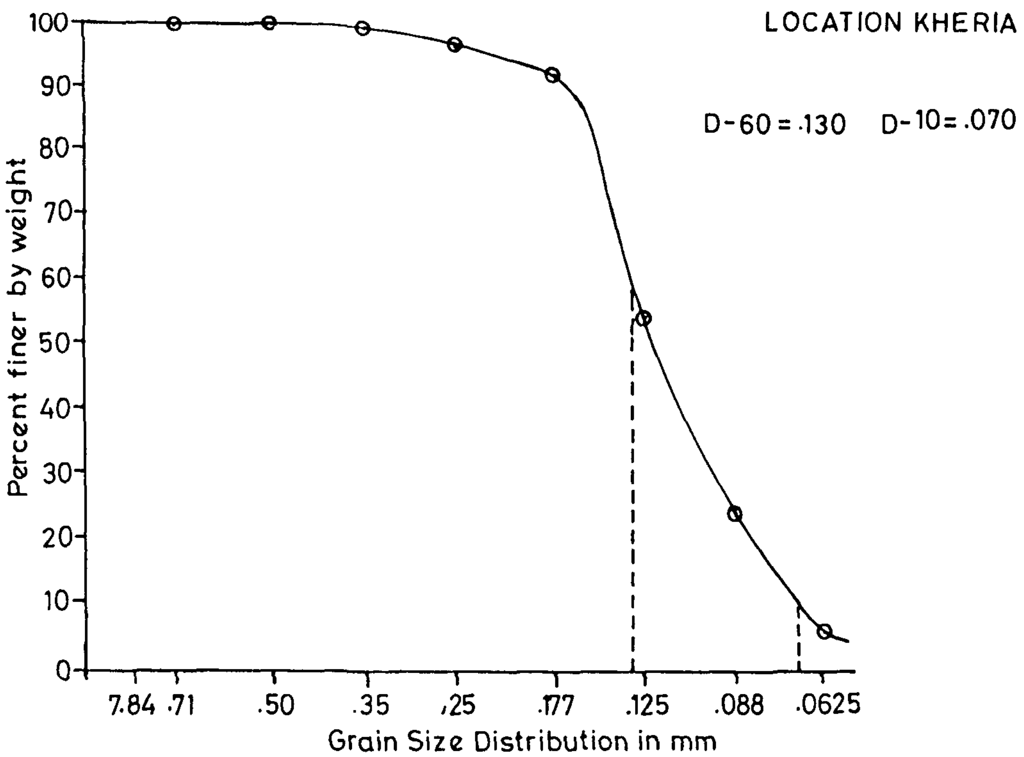
Where the value of A is established as 6 for sandy aquifer.

In the present study, aquifer materials were collected from the available drilling sites. Besides, sand samples were also collected from the Ganga and Kali beds through trenching and three samples were collected at the interval of 30 cm from each trench, later on, these samples were mechanically analysed.

The equipment required for sieve analysis includes a small hot plate for drying the samples, a set of standard testing sieves and accurate physical balance for weighing the aquifer materials. A representative sample 100-200 grams was taken in laboratory by coning and quatering, oven dried and exact weight

FIG.25-a

GRADING CURVES OF AQUIFER SAMPLES



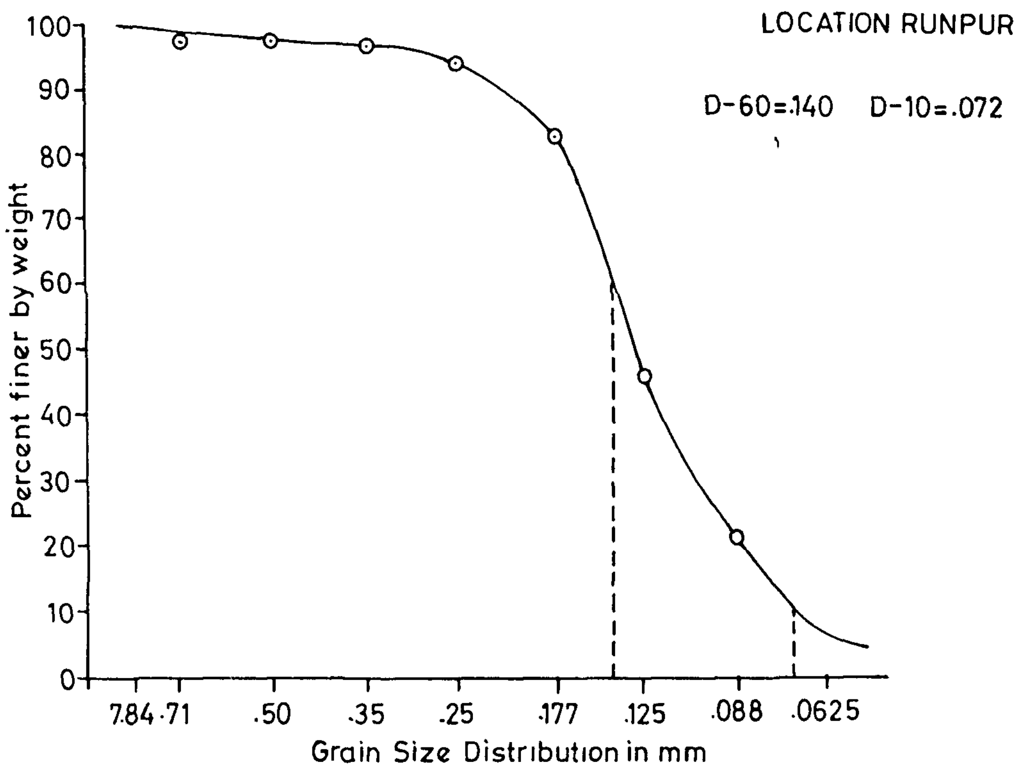
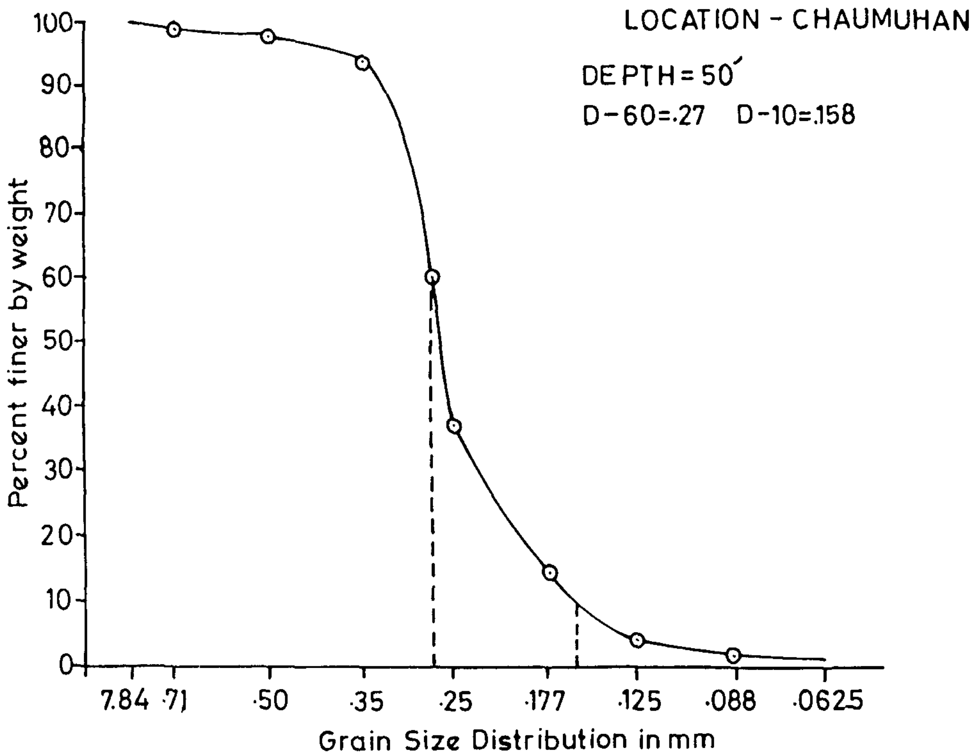


FIG. 25-a

GRADING CURVES OF AQUIFER SAMPLE



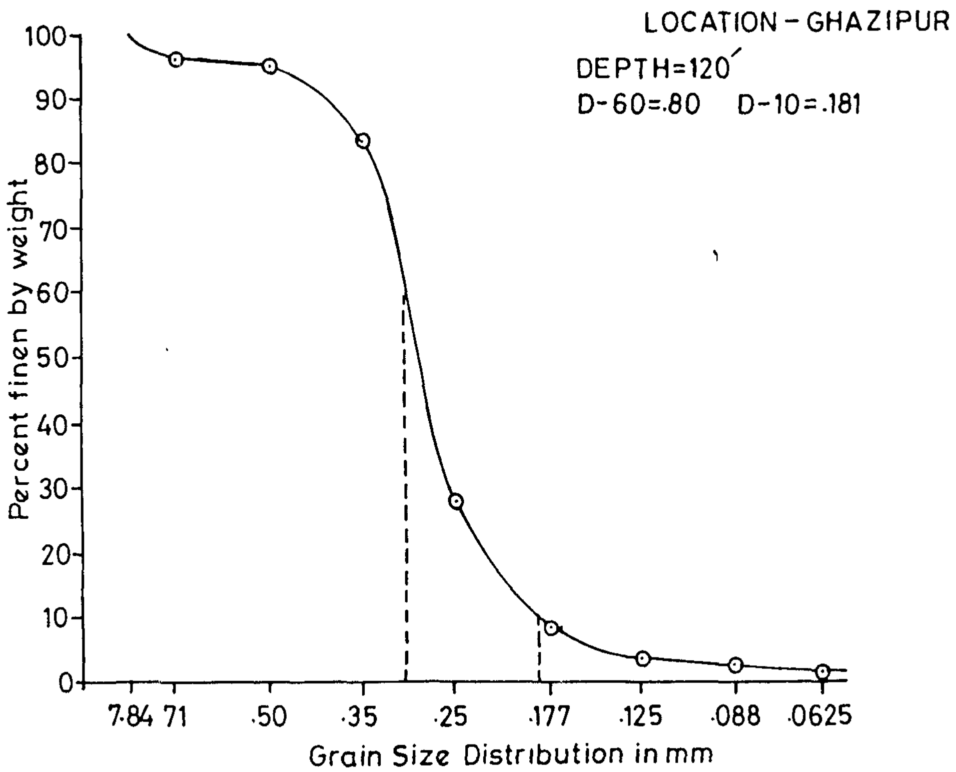
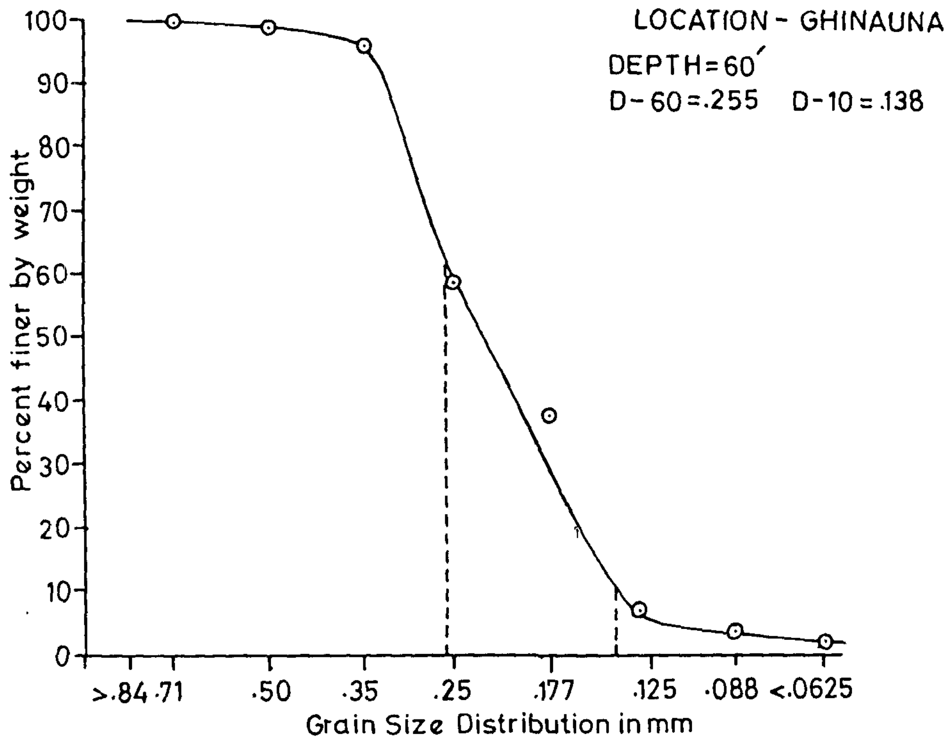
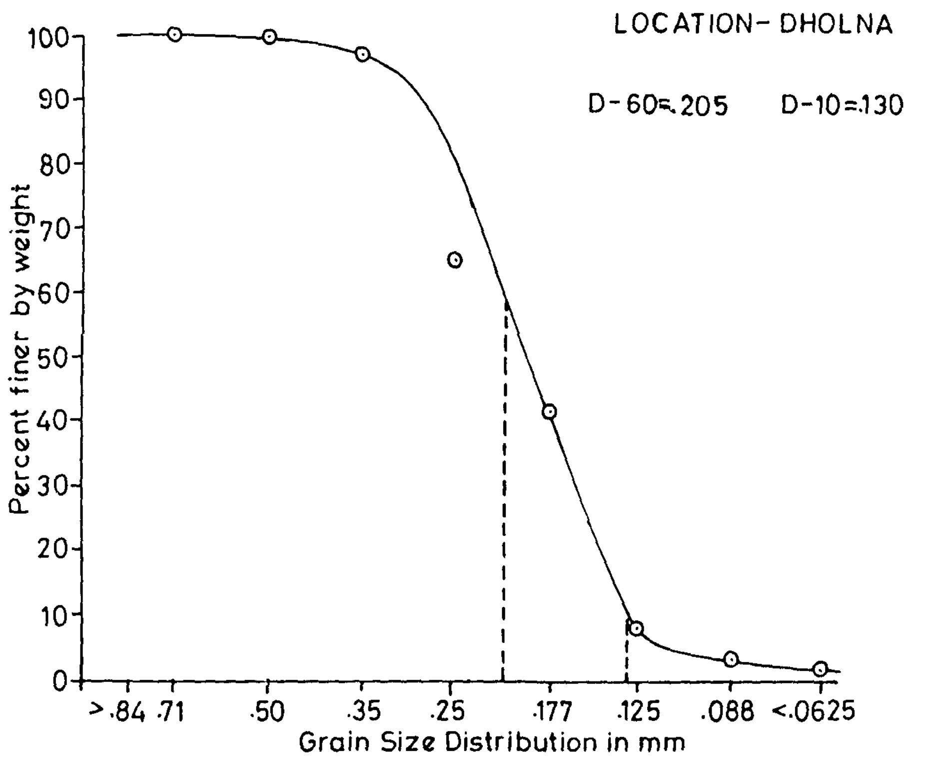


FIG. 25-a

GRADING CURVES OF AQUIFER SAMPLES





GRADING CURVE OF AQUIFER SAMPLE

FIG.25-a

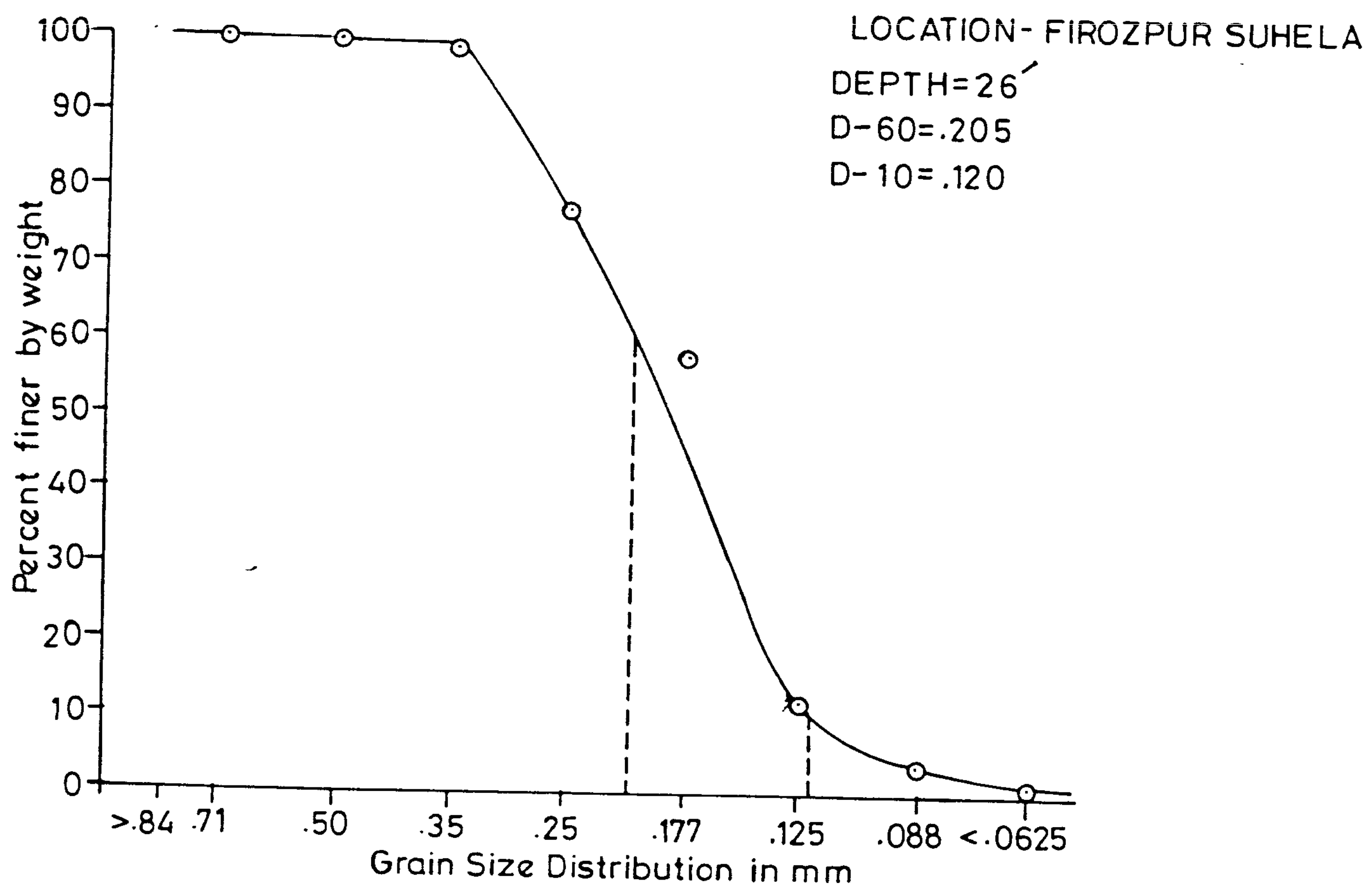
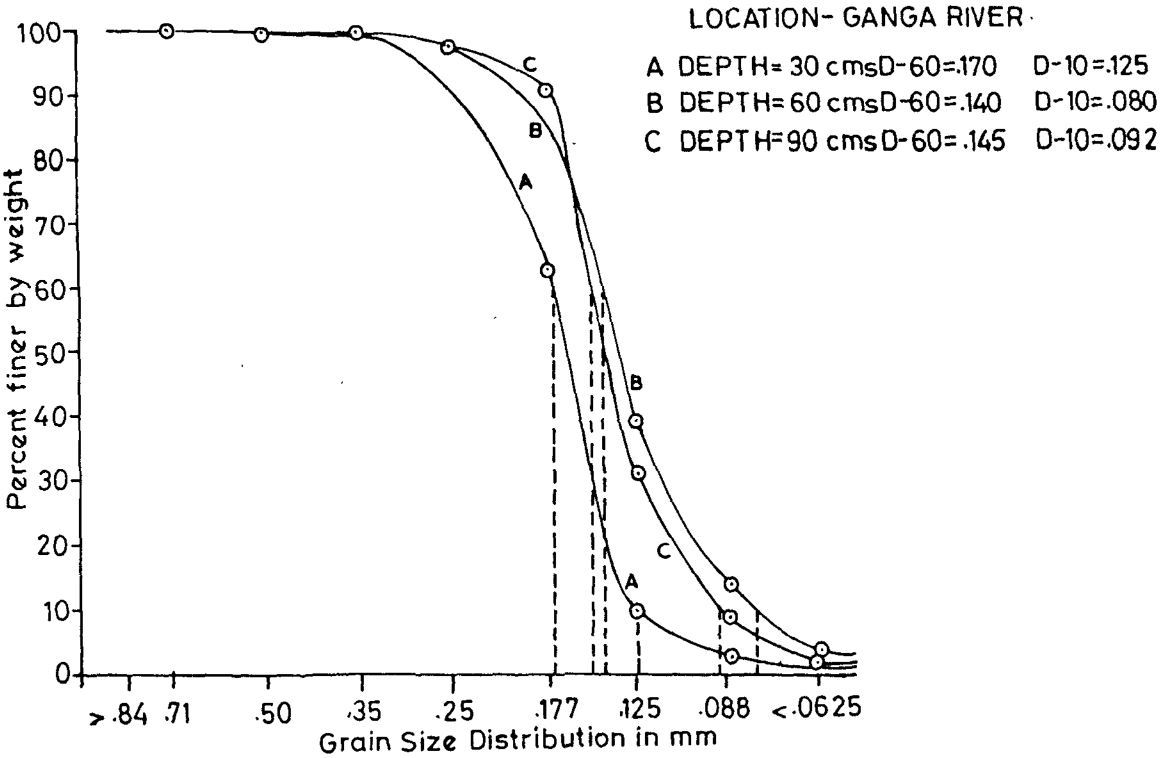


FIG.25-b


LOCATION- GANGA RIVER
A DEPTH= 30 cms D-60=.170 D-10=.125
B DEPTH=60 cms D-60=.140 D-10=.080
C DEPTH=90 cms D-60=.145 D-10=.092
Percent finer by weight
100
90
80
70
60
50
40
30
20
10
0
>.84 .71 .50 .35 .25 .177 .125 .088 <.0625
Grain Size Distribution in mm
A
B
C

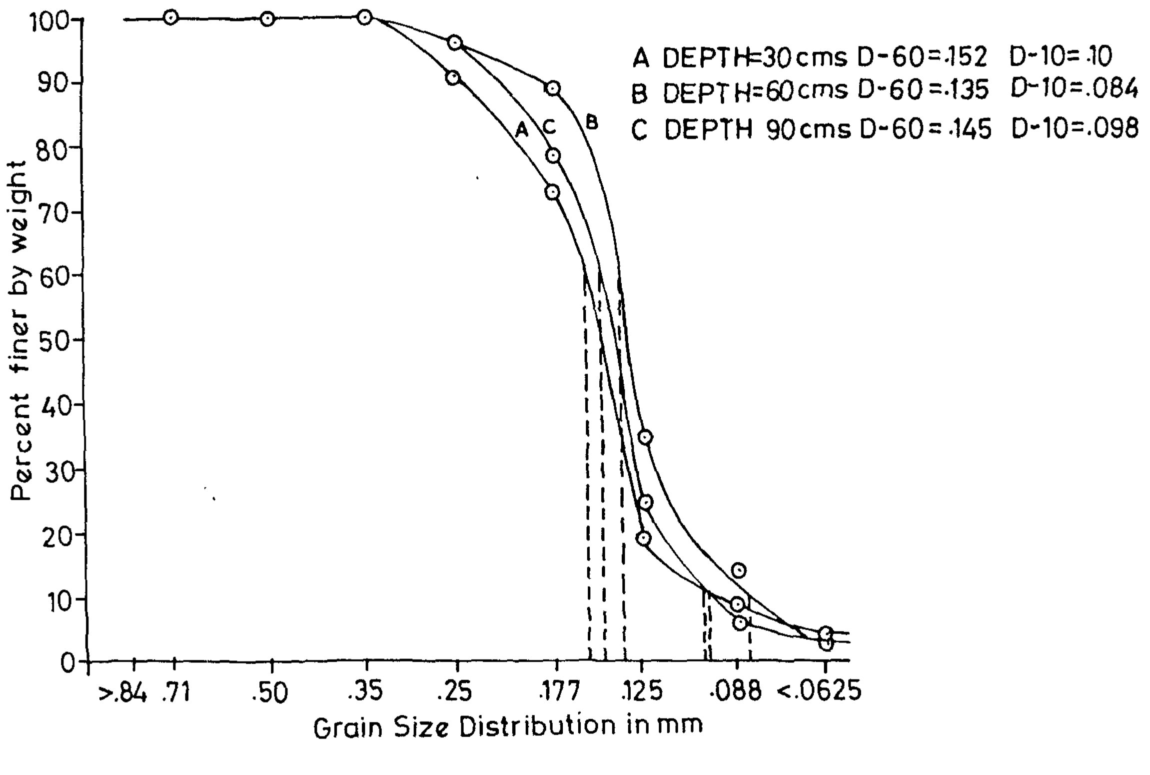
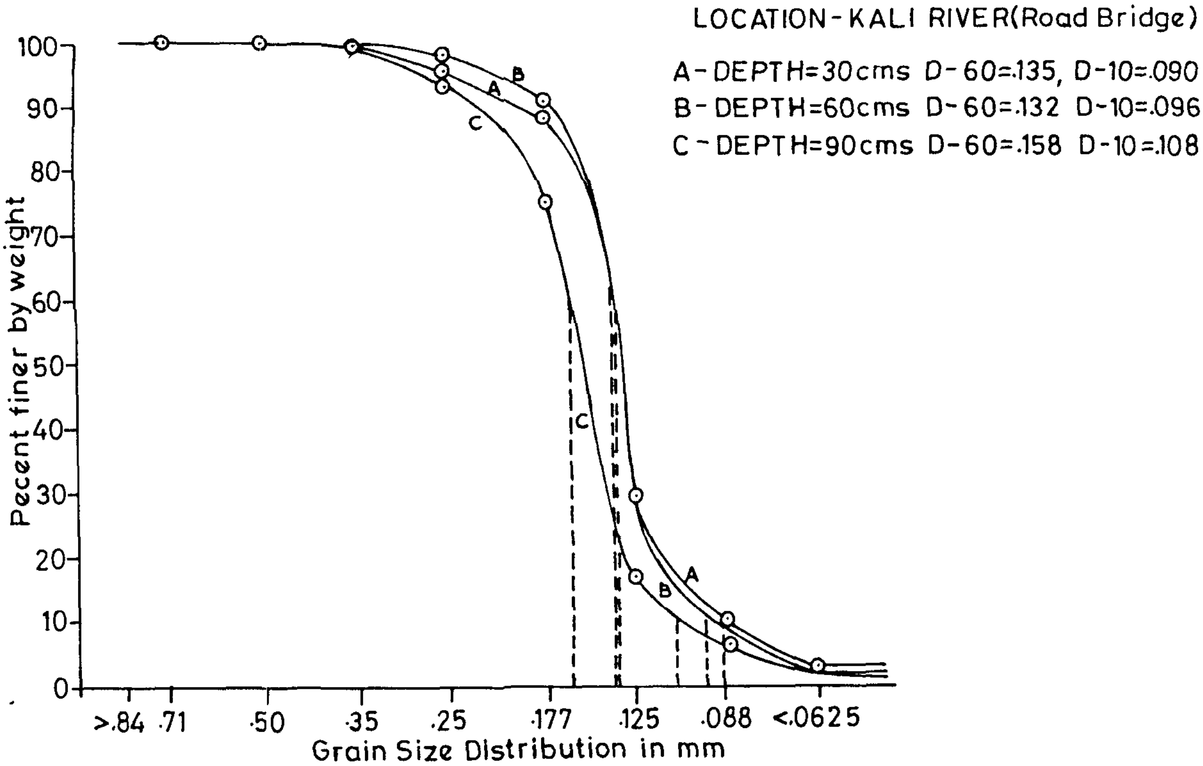
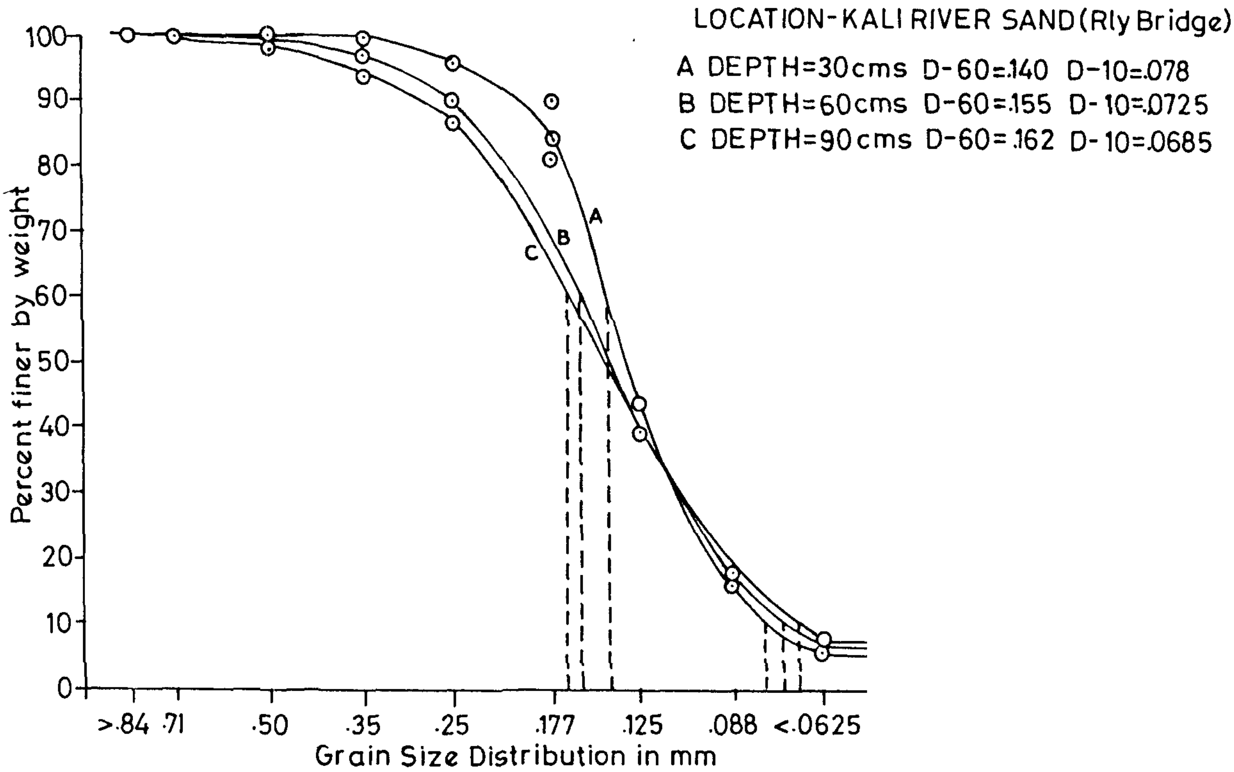

A DEPTH=30cms D-60=.152 D-10=.10
B DEPTH=60cms D-60=.135 D-10=.084
C DEPTH 90cms D-60=.145 D-10=.098
Percent finer by weight
100
90
80
70
60
50
40
30
20
10
0
>.84 .71 .50 .35 .25 .177 .125 .088 <.0625
Grain Size Distribution in mm
A
B
C

FIG. 25-c

GRADING CURVES OF SAND SAMPLE OF KALI RIVER





poured into the top sieve and covered with lid. The whole nest was shaken through electrical sieve shaker for about 15 minutes and material retained in each sieve was accurately weighed and data obtained were statistically analysed (Appendix III A, B & C). Percentage of material passing through each sieve gave a point on grading curve. The grading curve (Fig. 25a, b & c) was plotted on a semi-log paper and the following parameters were determined.

Effective Size : The term effective size was developed by Allen Hazen (1892) in his studies of filter sands. He defined it as particle size where 10% of sand is finer and 90% coarser. It is accepted that d_{10} is the most important parameter among those governing the permeability properties of a medium (Marsily, 1986).

Uniformity Coefficient (Cu) - is average slope of the grading curve between 10% and 60% size and is given by

$$Cu = \frac{D_{60}}{D_{10}}$$

It gives an idea of grading of particle size distribution in the material, lower values of Cu < 2 indicate more uniform material or poor grading, higher values indicate well graded material and are indicative of lower porosity (Raghunath, 1987).

Hydraulic Conductivity (K)

Hydraulic conductivity was evaluated by using formula of Uma, et al. (1989)

$$K = A\, d_{10}^2$$

where,

A = 6

d_{10} = effective grain size

The result of size analysis shows that the effective grain size of aquifer material ranges between 0.07 to 0.181 mm which shows that the sand size ranges between medium to fine. The effective grain size of the Ganga sediment ranges between 0.08 to 0.125 mm while the effective size of Kali sediments ranges between 0.068 to 0.108 mm which reveals that the Kali sediments are finer than the ganga alluvium.

Uniformity coefficient of the aquifer material is given in (Table 6 a).

Table 6 a : Showing the value of effective size, Uniformity coefficient and hydraulic conductivity (K). Calculated by statistical grain size method.

Sl. No.	Location	Effective grainsize (d_{10})	Uniformity Coefficient (Cu)	Hydraulic conductivity cms^{-1}	m/day
1.	Chaumuhan	0.158	1.70	0.149	129.4
2.	Gazipur	0.181	4.41	0.196	169.83
3.	Runpan	0.072	1.94	0.031	26.87
4.	Kheria	0.070	1.85	0.029	25.40
5.	Dholna	0.13	1.57	0.101	87.60
6.	Firozpur Suhela	0.120	1.70	0.086	74.3
7.	Ghinauna	0.138	1.63	0.114	98.72

A perusal of table shows that uniformity coefficient ranges between 1.57 to 1.85 except at Ghazipur, the sample shows the Cu values as 4.41. The results of uniformity coefficient reveal that most of the samples show value of Cu < 2 hence their porosity is high i.e. they are uniform. The uniformity coefficient of the Ganga sediment (Table 6 b) ranged between 1.36 to 1.75. It also shows lower values for Cu i.e. < 2 which indicates that the Ganga sediment is poorly graded, i.e. their porosity is high. The samples from the Kali river show higher value of Cu than the Ganga sediments which range between 1.37 to 2.45 and indicates that the porosity of Kali sediments is slightly lower than the Ganga sediments. The hydraulic conductivity of the aquifer material, calculated by Uma et al., (1989) formula, ranges between 25.4 to 169.8 m/day while that of the Ganga sediments ranges between 33.17 to 81.00 m/day. The hydraulic conductivity of the Kali sediments varies between 23.97 to 60.46 m/day.

Table 6 b : Value of effective size, uniformity coefficient and hydraulic conductivity (K), of the Kali and the Ganga sediments, calculated by statistical grain size method.

Location	Depth	Effective grain size (d_{10})	Uniformity coefficient (C_u)	Hydraulic conductivity (K) cms^{-1}	Hydraulic conductivity m/day
Kali River-1	30	0.078	1.78	0.36	31.53
	60	0.072	2.15	0.031	26.87
	90	0.068	2.38	0.027	23.97
Kali River-2	30	0.09	1.5	0.048	41.99
	60	0.096	1.37	0.055	47.77
	90	0.108	1.46	0.069	60.46
Ganga River-1	30	0.125	1.36	0.093	81.00
	60	0.08	1.75	0.038	33.17
	90	0.092	1.57	0.050	43.87
Ganga River-2	30	0.10	1.52	0.050	51.84
	60	0.084	1.60	0.042	36.57
	90	0.098	1.47	0.057	49.78

The aquifer materials collected from the Kheria and Runpan drilling sites close to Atrauli town were mechanically analysed and the value of K were determined through Uma formula. These values were further compared with the values of K determined through the pumping test and data analysis at Atrauli Test well site.

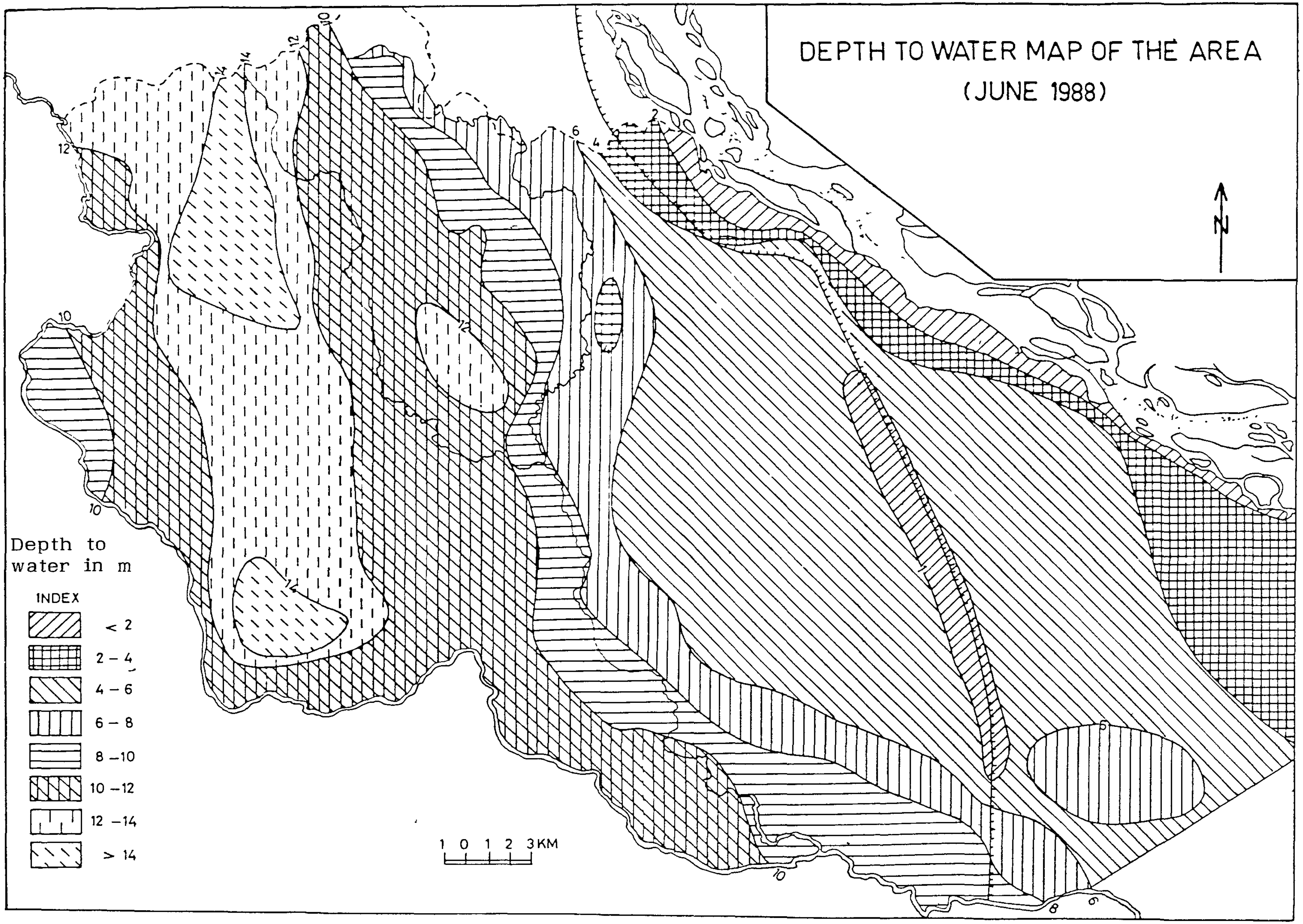
The values of K determined through Uma formula ranges between 25-26 m/day while the value of K determined through the pumping test is 22 m/day. This shows that the value of K determined through uma formula is slightly on higher side than one determined through the pumping test, which may be due to the disturbance of natural setup of the aquifer material.

Depth to Water Table

In an unconfined aquifer, the water table is the upper surface of the zone of saturation where the pressure is atmospheric. It is defined by the level at which water stands in wells penetrating the aquifer, just enough to hold standing water. However, in general the water level standing in dugwells are considered accurate enough to represent water table of an area. The depth to water maps depict the regional variations of the water level with respect to land surface all over the area.

The water table maps are useful in deciphering the area of recharge and discharge. Recharge areas are characterized by

FIG 26-a


DEPTH TO WATER MAP OF THE AREA
(JUNE 1988)
N
Depth to
water in m
INDEX
< 2
2 – 4
4 – 6
6 – 8
8 – 10
10 – 12
12 – 14
> 14
1 0 1 2 3 KM
10
12
14
6
4
2
8

deeper water table while shallow water table below and surface indicates discharge area (Feter, 1988).

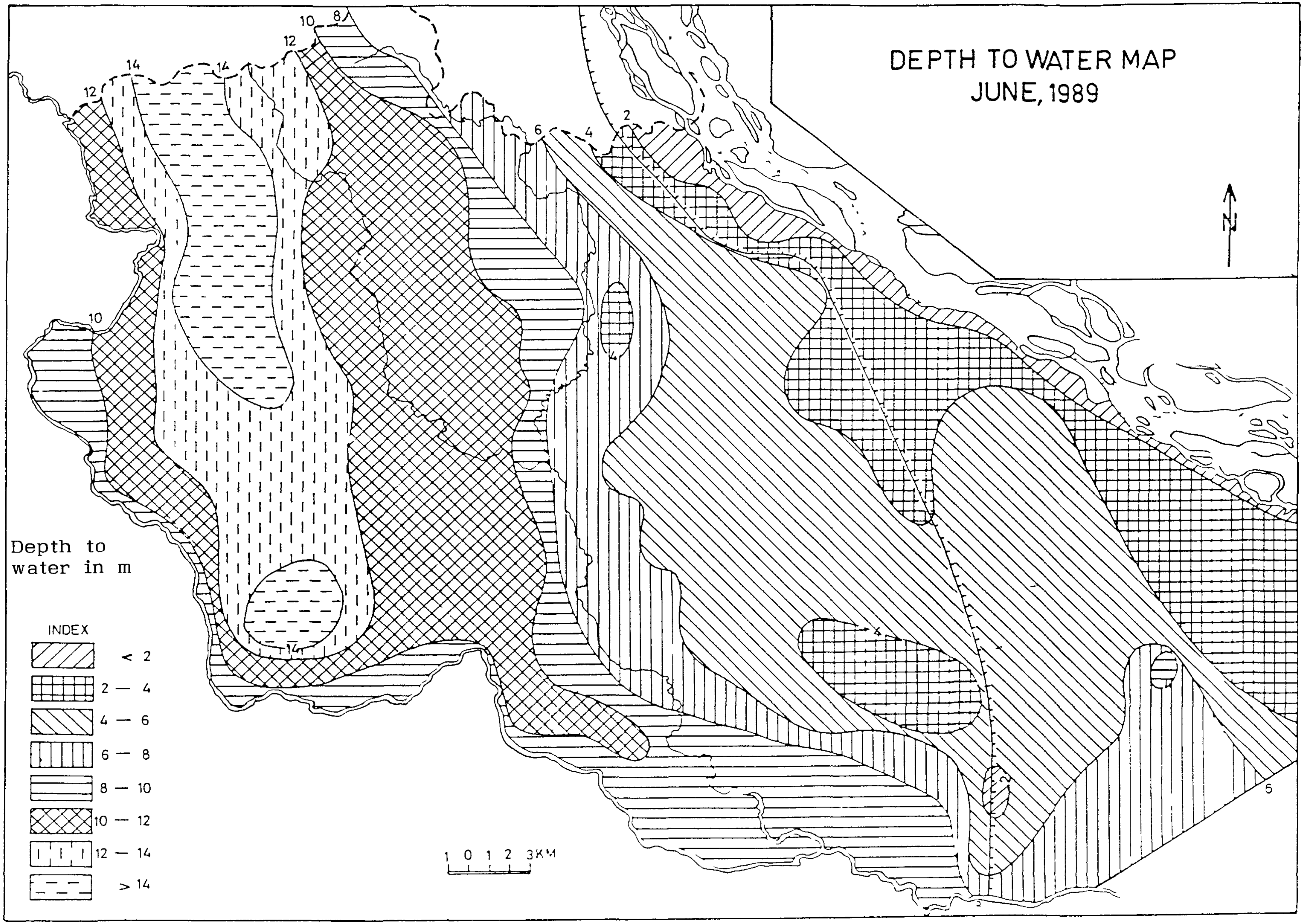
Water level data of open wells (Appendix IV A & B) evenly spaced at a distance of two kilometers were utilized to prepare epth to water map of the study area.

Figures 26a & **27a** shows depth to water for the pre-monsoon (June 1988, 1989) and (Figs. 26b & 27b) show depth to water for post monsoon period (November, 1988, 1989).

Depth to Water Table (Pre-monsoon, 1988, 1989)

In pre-monsoon (1988 June) the depth to water ranges between 1.85 to 16 metres below the ground level, while in 1989 it ranges between 1.6 to 16.2 metres below ground level. The area has been divided into 9 depth to water level zone's varying from (1) $\angle$2 (2) 2 to 4 (3) 4-6 (4) 6-8 (5) 8-10 (6) 10-12 (7) 12-14 and (8) 14 - 16 metre below the ground level. The deeper water levels viz. 15 and 16 metres b.g.l. were recorded at Atrauli and Sunhera villages respectively in the upland area and shallowest 1.85 and 1.65 metres below ground level at Dinapur in the low valley of the Ganga.

A perusal of the maps show that in low valley of the Ganga which is topographyically low area in general, the water table ranges between 2 to 4 metre below the ground level. At places, close to the upland margins, the water table is observed to be


DEPTH TO WATER MAP
JUNE, 1989
N
Depth to
water in m
INDEX
< 2
2 — 4
4 — 6
6 — 8
8 — 10
10 — 12
12 — 14
> 14
1 0 1 2 3 KM
2
4
6
8
10
12
14

comparatively deep (8 metre) than the general depth to water level in the low valley. This is probably because of the fact that these places are located at topographically high ground. In the vicinity of the Lower Ganga Canal the water table is generally 2 m or less than 2 metres below the ground level which is the resultant effect of the quantum of seepage that has been taking place ever since the commissioning of the lower Ganga canal, in 1879. The excessive seepage is taking place through unlined canal bed and consequently the general water table in the area proximal to the canal has progressively been rising.

In general, the water table map show a gradual increase in depth to water from east to west direction. In the area lying between the lower Ganga canal and Nim river there is a network of canal, which recharges the shallow aquifers proportionate to their hydraulic properties, hence the water table in the tract generally ranges between 4 to 6 metre below ground level. The deeper water level zones, that is 6 to 8, 8 to 10, 10 to 12, 12 to 14 and 14 to 16 metres below ground level were recorded in the Nim-Kali upland area. The deepest water level zones, where the water level ranges between 12 to 16 metres below the ground level was delineated between Atrauli town and the left bank of the Kali river. Atrauli town is located on the topographic high of the Kali-Nim interfluves which gradually slopes towards the kali bank. In this tract the water level has been declining since the last two decades due to the heavy withdrawals of the groundwater for irrigation for the shallow farmers tubewells spaced at about 100 metres intervals. In comparison to the Ganga-Nim upland which is cris-crossed by the canal networks, the Nim-Kali upland is completely bereft of canal and all water demands are met through the ground water, consequently the impact is decline in water level at the rate of 0.34 m/year since late sixties. It is really very interesting to note that on one part Ganga-Nim upland is facing water logging situation due excessive seepage while, the Nim-Kali upland is beset with the declining trend caused due to excessive withdrawals. The table 7 below shows number and percentage of wells falling in different depth to water zones.

Table 7 a : DEPTH TO WATER (JUNE, 1988, 1989)

Year		Depth to Water range in (m)							
		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16
	No. of wells	2	23	36	23	30	21	18	7
1988	160	1.25%	14.3%	22.5%	14.37%	18.75%	13.12%	11.25%	4.37%
1989	156	6 3.8%	30 19.62%	25 15.18	24 15.18%	24 15.18%	24 15.18%	15 9.5%	8 5.06¢
Average %		2.52	16.96	18.89	14.77	16.96	14.47	16.377	4.71

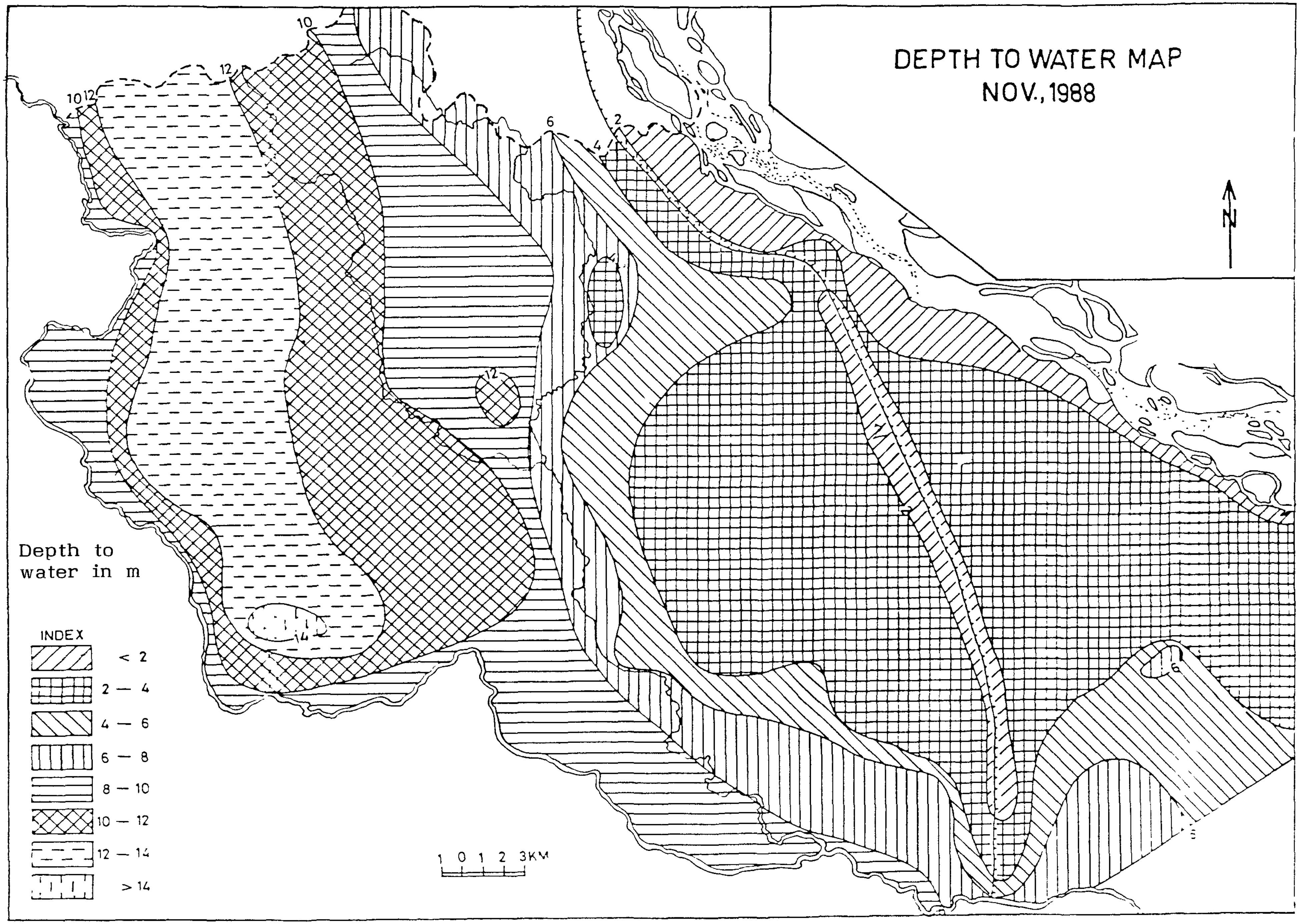
It may be seen that during pre-monsoon period, 57.49% of wells show depth to water level ranging between 6 to 14 m below ground level, 36.8% of wells 2 to 6, 1.25% less than 2 metres, and 4.37% of the wells showing more than 16 metres. Similarly during post-monsoon period, 52.49% of wells are recorded showing the depth to water level ranging between 6 to 14 metres, 36.87 well 2 to 6 metres, 10% of the wells less than 2 metres and 0.5% showing more than 14 metres.

Table 7 b : DEPTH TO WATER (NOV. 1988, 1989)

Year		Depth to Water range (m)							
		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16
	No.of wells	16	37	22	23	22	20	19	1
1988	160	10%	23.12%	13.75%	14.37%	13.75%	12.15%	11.87%	0.62%
1989	156	10	37	20	24	20	25	12	7
		6.3%	24%	12.65%	15.18%	12.65%	16.45%	7.59%	4.43%
Average %		8.15	23.56	13.2	14.77	13.2	14.3	9.73	2.71

A comparison of the two tables show that the percentage of wells recording depth to water less than 2 metres is increased by 8.75% during post monsoon, and there is decrease by 3.7% in the value of wells recording the depth to water more than 14 metre recorded during the pre-monsoon. This change in the values is due to the recharge of aquifers through rainfall.

FIG. 26-b


DEPTH TO WATER MAP
NOV., 1988
N
10
12
10
12
6
4
2
12
14
6
1 0 1 2 3KM
Depth to water in m
INDEX
< 2
2 — 4
4 — 6
6 — 8
8 — 10
10 — 12
12 — 14
> 14

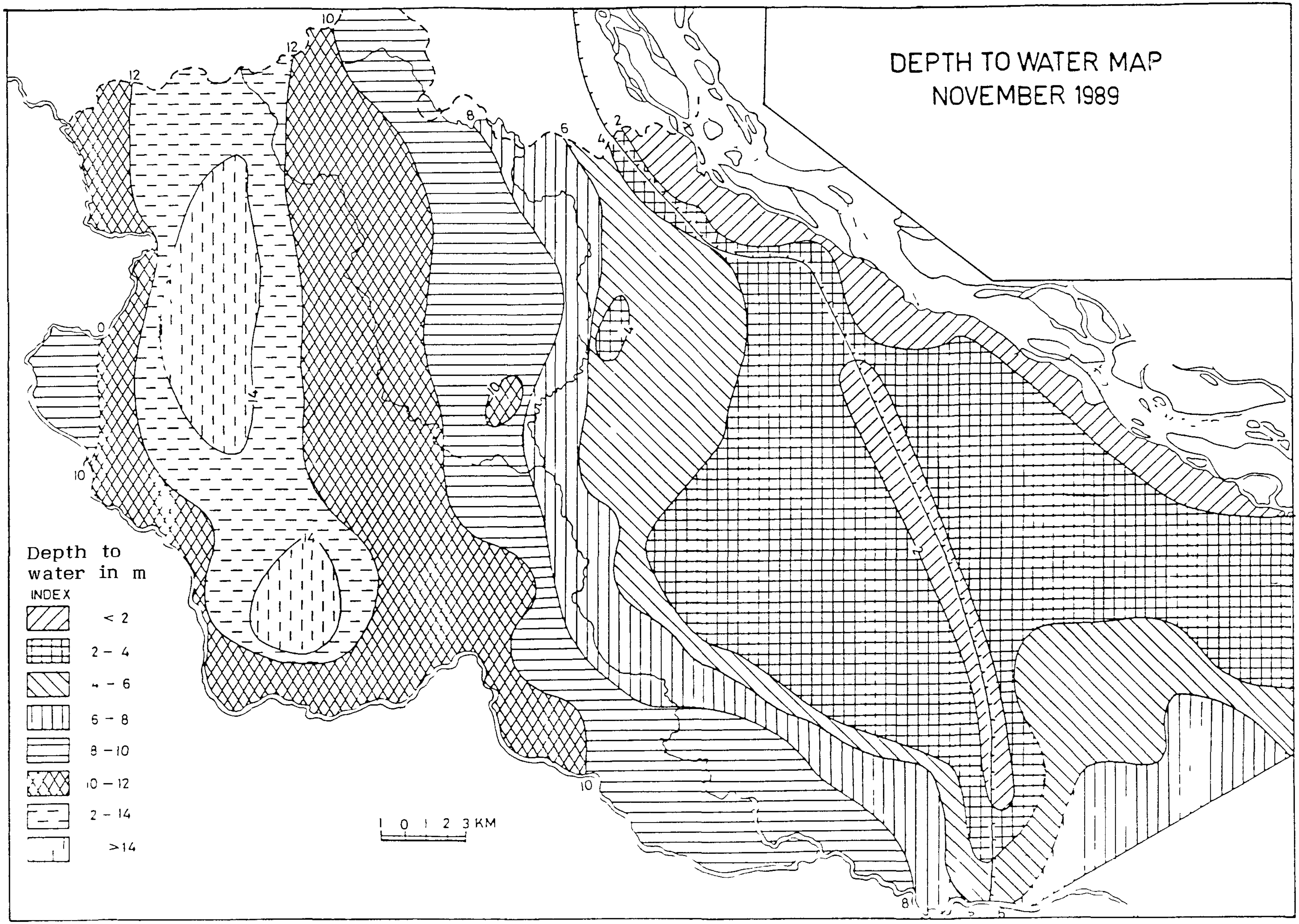
A comparative study of the pre-monsoon depth to water maps of 1988 and 1989 reveals that the water level during 1988 was recorded slightly deeper in all observation wells than that of pre-monsoon water level during 1989 except Atrauli area. This difference in pre-monsoon water levels between 1988 and 1989 was probably caused due to severe drought during 1987 while there was a heavy rainfall during 1988.

Post monsoon depth to water table

Figures 26b & 27b shows the depth to water of post-monsoon (November, 1988, 1989).

A perusal of fig. shows that during November, 1988, 1989, the shallowest water level i.e. 1.15 m b.g.l. was recorded at Dinapur while the deepest level i.e. 15 m was observed at Nausha observation well close to the left bank of the Kali river. In Nim-Kali upland area particularly around Atrauli, the depth to water level was measured as 14 metres below ground level.

Shallow water table leading to swampy conditions during and after monsoon season is characteristic feature of the low valley of the Ganga, and Lower and Upper Ganga canal command areas. During the year 1988, the area recorded highest rainfall of the decade and consequently a sharp rise in water table was recorded all over the area which further resulted in the large fluctuation of water levels. The post-monsoon depth to water map of 1989 does


DEPTH TO WATER MAP
NOVEMBER 1989
Depth to water in m
INDEX
< 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14
>14
1 0 1 2 3 KM
12
10
14
8
6
4
2
5

not show any significant difference. This is caused due to the deficient rainfall during 1989.

In general depth to water zones described are found in confirmity with the general physiographic unit of the area.

Water Level Fluctuations

Figure 28a & 28b shows water level fluctuation in the area. The fluctuations are represented by way of contours of water level difference in pre-monsoon and post-monsoon water levels for the period of June and November, 1988 and 1989. This difference in groundwater levels show a seasonal pattern of fluctuations.This results from influence such as rainfall and irrigation pumping that follow well defined seasonal cycles (Todd, 1980).

A perusal of fluctuation map (Fig. 28 a) shows that with an interval of 0.5 m, the area is divisible into the following four distinct water level fluctuation zones. Table gives the number of wells falling in different fluctuation zones.

FIG 28-a

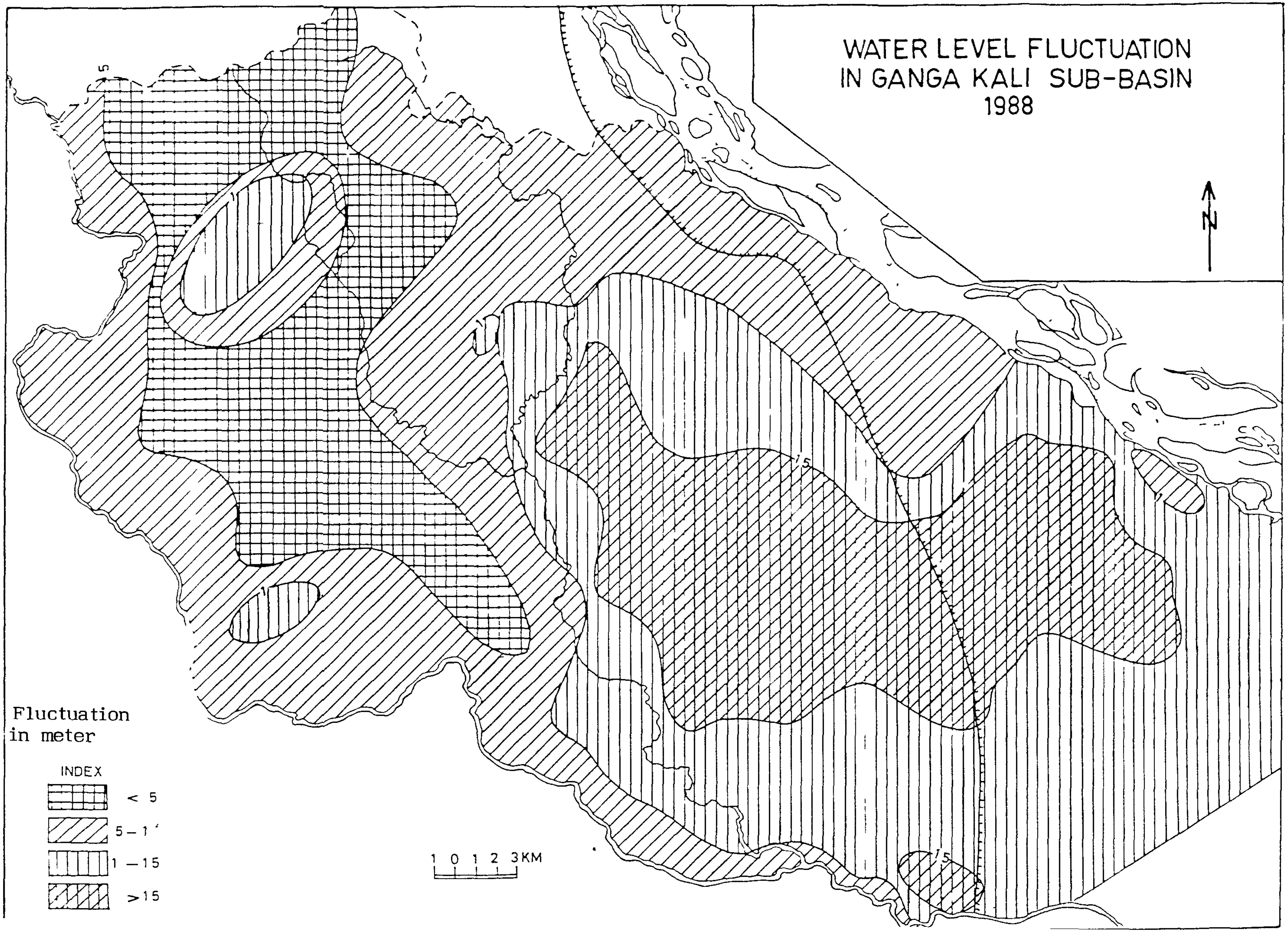

WATER LEVEL FLUCTUATION
IN GANGA KALI SUB-BASIN
1988
N
Fluctuation
in meter
INDEX
< 5
5 – 1'
1 – 15
> 15
1 0 1 2 3 KM
15
15
5

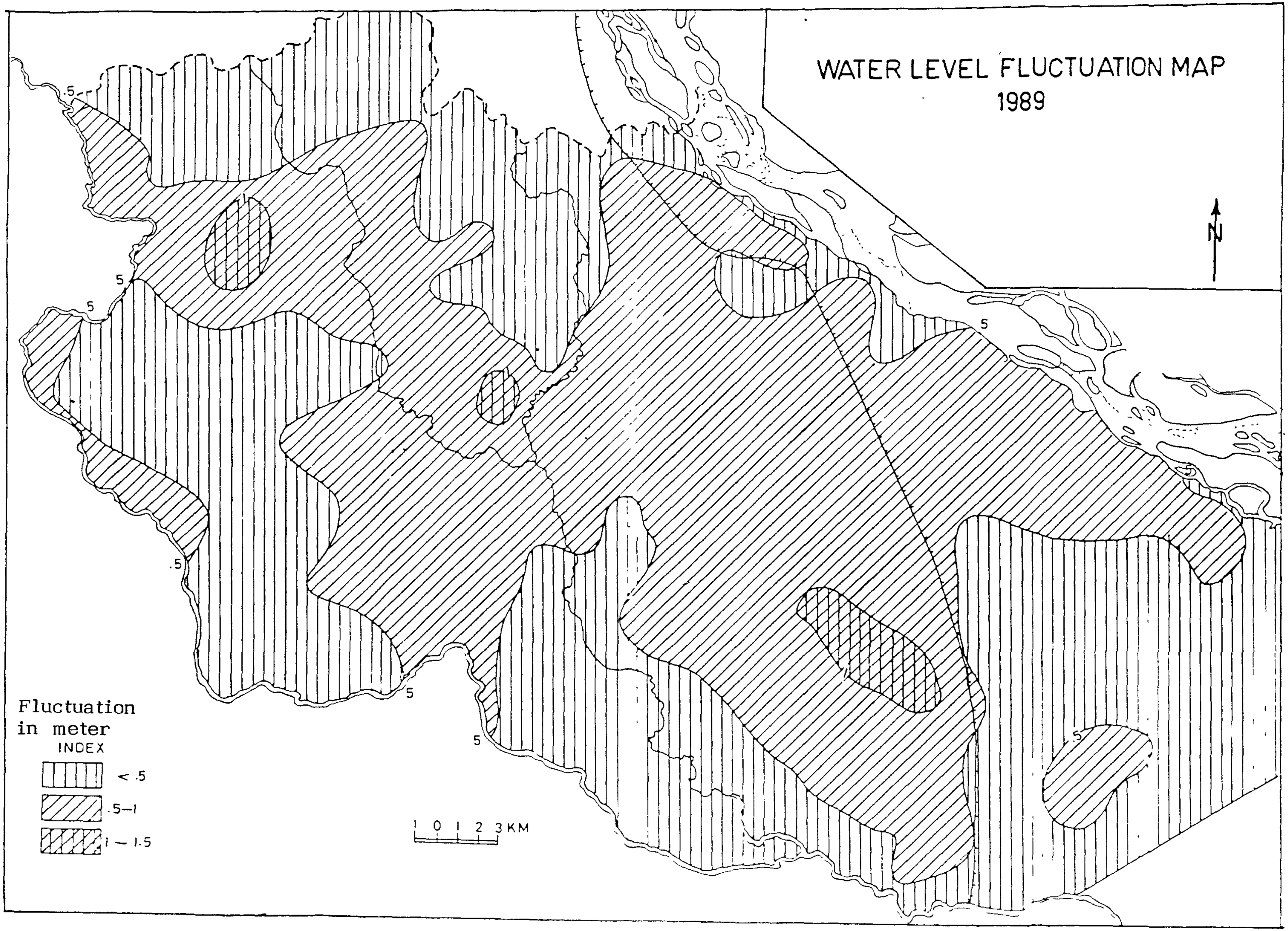
Table 8 : Pre-monsoon and Post-monsoon fluctuation.

Year		Fluctuation Range (m)			
		0-0.5	0.5-1	1-1.5	1.8
	No. of wells	23	56	53	28
1988	160	14.37%	35%	33.12%	17.5%
1989	158	72	76	10	-
		45.56%	48%	6.3%	-

Further, table shows that in the major part of the area the fluctuation ranges between 0.5 to 1.0 metre and is followed by the zone showing fluctuation in the range of 1 to 1.5. A very small portion of the area is covered by the fluctuation of <·5 m.

The figure shows that in southern part of the low valley of the Ganga lying east of Kasganj and west of present active channel, the water level fluctuation ranges between 1 to 1.5 and > 1.5 metres which is the highest recorded fluctuation in the area.

This is at variance to the northern portion of the valley where the fluctuation ranges between 0.5 to 1 metre. This variation in fluctuation in the low valley of the Ganga itself is probably due to the lithological control which is further substantiated by the


WATER LEVEL FLUCTUATION MAP
1989
N
Fluctuation
in meter
INDEX
< .5
.5—1
1 — 1.5
1 0 1 2 3 KM
.5
5
.5
5
5
5
.5

sand percent map. This zone is followed due west by 1 to 1.5 metre fluctuation zone in the eastern part of the Nim-Kali upland tracts. In the middle of Nim-Kali upland is situated Atrauli town where the fluctuation have been recorded to range between 1 - 1.5 metre. Further west, in the area close to the left bank of Kali river, the fluctuation ranges between 0.5 - 1.0 m only.

From the above it would be apparent that these high fluctuation areas are also recharge area and the area of high elevations.

The fluctuation map of 1989 (Fig. 28b) does not show any significant change in water level. This is caused due to deficient rainfall during the year.

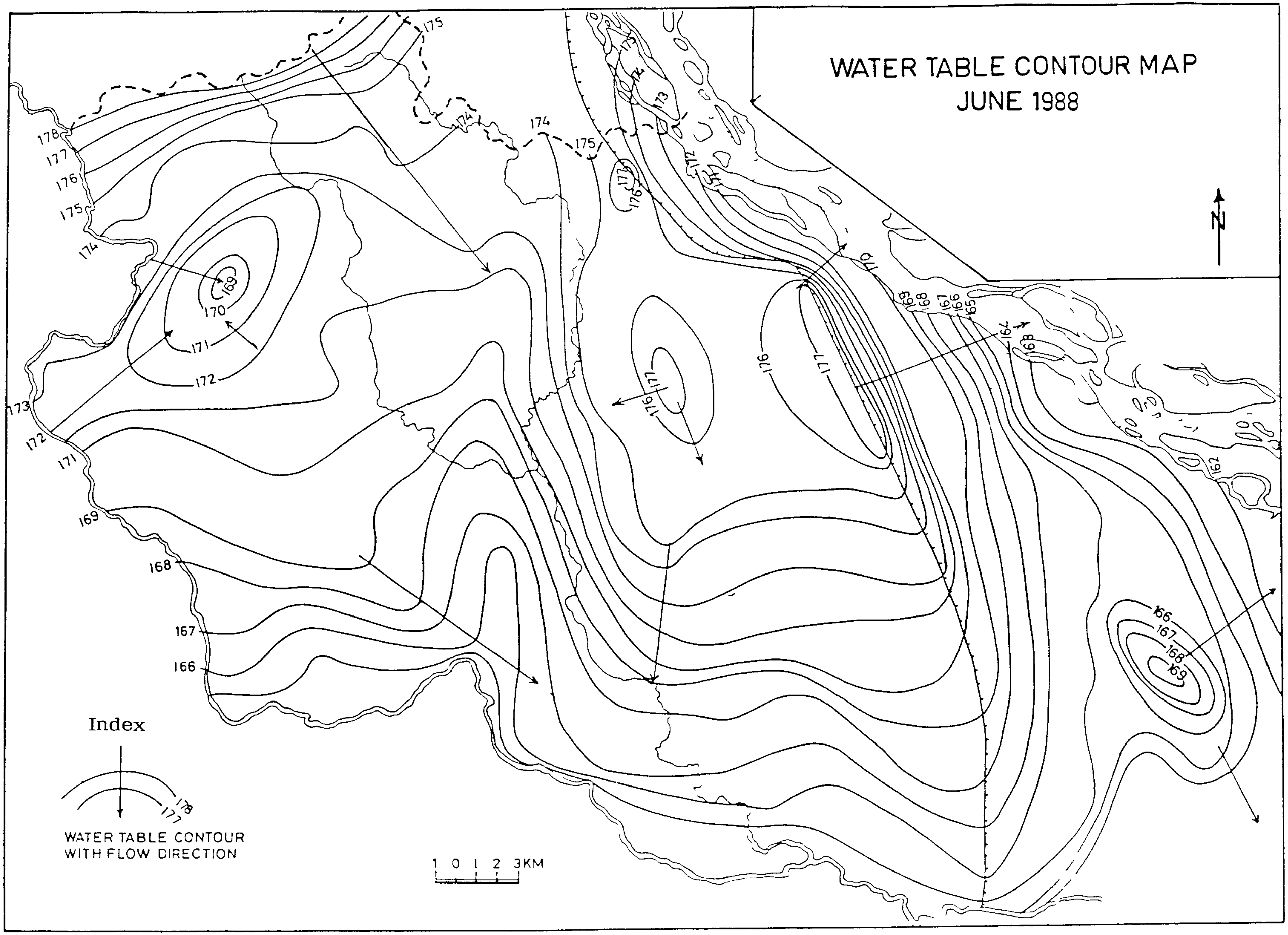
GROUNDWATER MOVEMENT

Water Table Contour Maps

Water level data of wells collected during pre-monsoon, and post-monsoon (1988, 1989) were analysed and altitudes of water level with reference to mean sea level were plotted and water table contour maps were prepared with contour interval of one metre.

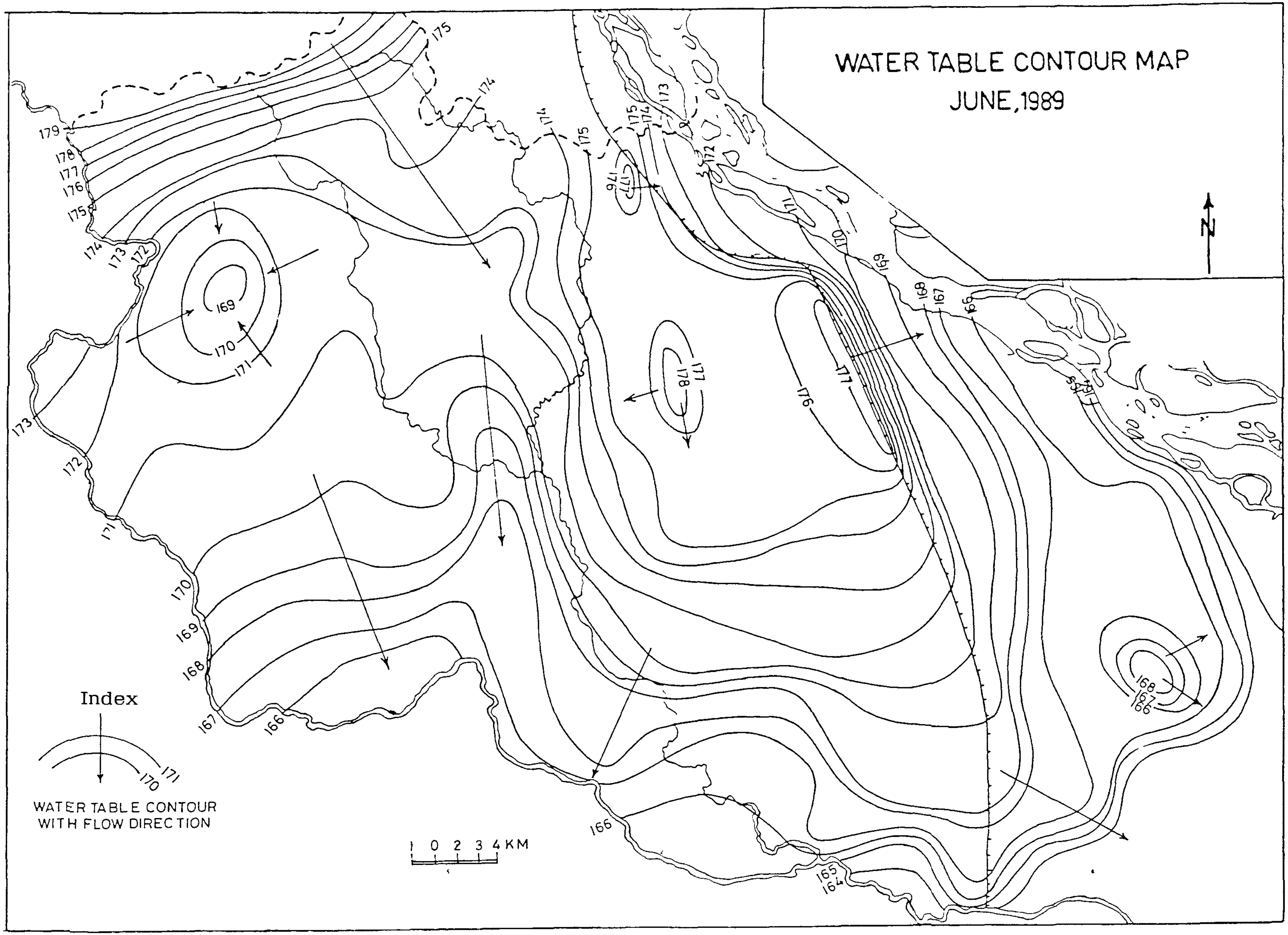
The water table contour maps are very useful in deciphering the groundwater flow direction, hydraulic gradient and area of recharge and discharge. Convex contours indicate area of groundwater recharge, while concave contours show tract of groundwater discharge (Todd, 1980). Further the divergence of flow lines indicates a recharge area whereas covergence of flow lines

FIG 29 - a



WATER TABLE CONTOUR MAP
JUNE 1988
N
178
177
176
175
174
173
172
171
170
169
168
167
166
165
164
163
162
Index
WATER TABLE CONTOUR
WITH FLOW DIRECTION
1 0 1 2 3KM

FIG 30-a


WATER TABLE CONTOUR MAP
JUNE, 1989
N
Index
171
170
WATER TABLE CONTOUR
WITH FLOW DIRECTION
1 0 2 3 4 KM
179
178
177
176
175
174
173
172
169
170
171
166
167
168
165
164

depicts the discharge area (Fetter, 1980).

Form and Slope of Water Table

The elevation of water table ranges between 179 metres in north west to 162 metres in south east above the mean sea level. A perusal of water table contour (Fig. 29a & 30a) shows that the general groundwater flow in consonance with the regional ground water flow direction in the central Ganga basin is from NW-SE direction.

However, at places there are some variations which are caused due to local factors in eastern flank groundwater flows due east and joins the river Ganga. From the western slope of the eastern upland groundwater flows from east to west and joins the Nim river. Similarly in Nim Kali upland groundwater flows from NW-SE direction. However, in the area close to the river Kali ground water flows from east to west direction and joins river Kali. In general the gradient varies from 0.4 m/km to 2.5 m/km.

In north eastern part of the area close to the lower Ganga canal and the Ganga river the hydraulic gradient is very steep i.e. 2.5 m/km. The steep hydraulic gradient is indicative of two factors viz. (Todd, 1980).

(1) heavy withdrawal

(2) low permeability

It has been observed during field studies that concentration of wells is relatively low in eastern part by which it can be assumed that steep gradient in this tract is due to low permeability horizons. However, this is also supplemented by the isopermeability map of the area which shows that this tract has real low permeability zones. The slope of water table is towards the river Ganga which depicts that the Ganga is effluent in nature. Similarly the river Kali which forms the western boundary of the study area is also effluent in nature. Further, there are three groundwater mounds along lower and upper Ganga canals (Fig. 29 & 30). One of these has formed in southeastern part of the area proximal to the right bank of upper Ganga canal, another mound has formed along the lower Ganga canal and third one has formed along the Farrukhabad branch of the lower Ganga canal. All these three mounds are the resultant effect of the excessive seepage of the canal water through the unlined canal into the shallow aquifers lying immediately below the canal beds. These mounds are shedding water from their eastern flank to the river Ganga and from their western flank to the Nim river. The aquifer system in this part is very much receptive of the massive seepage leading to the formation of these mounds.

However, perusal of the map (Fig. 29 & 30) also shows a groundwater trough around Atrauli which has developed due to heavy withdrawal of groundwater through shallow and deep tubewells. Here the groundwater flows from west to east which

FIG 29 - b

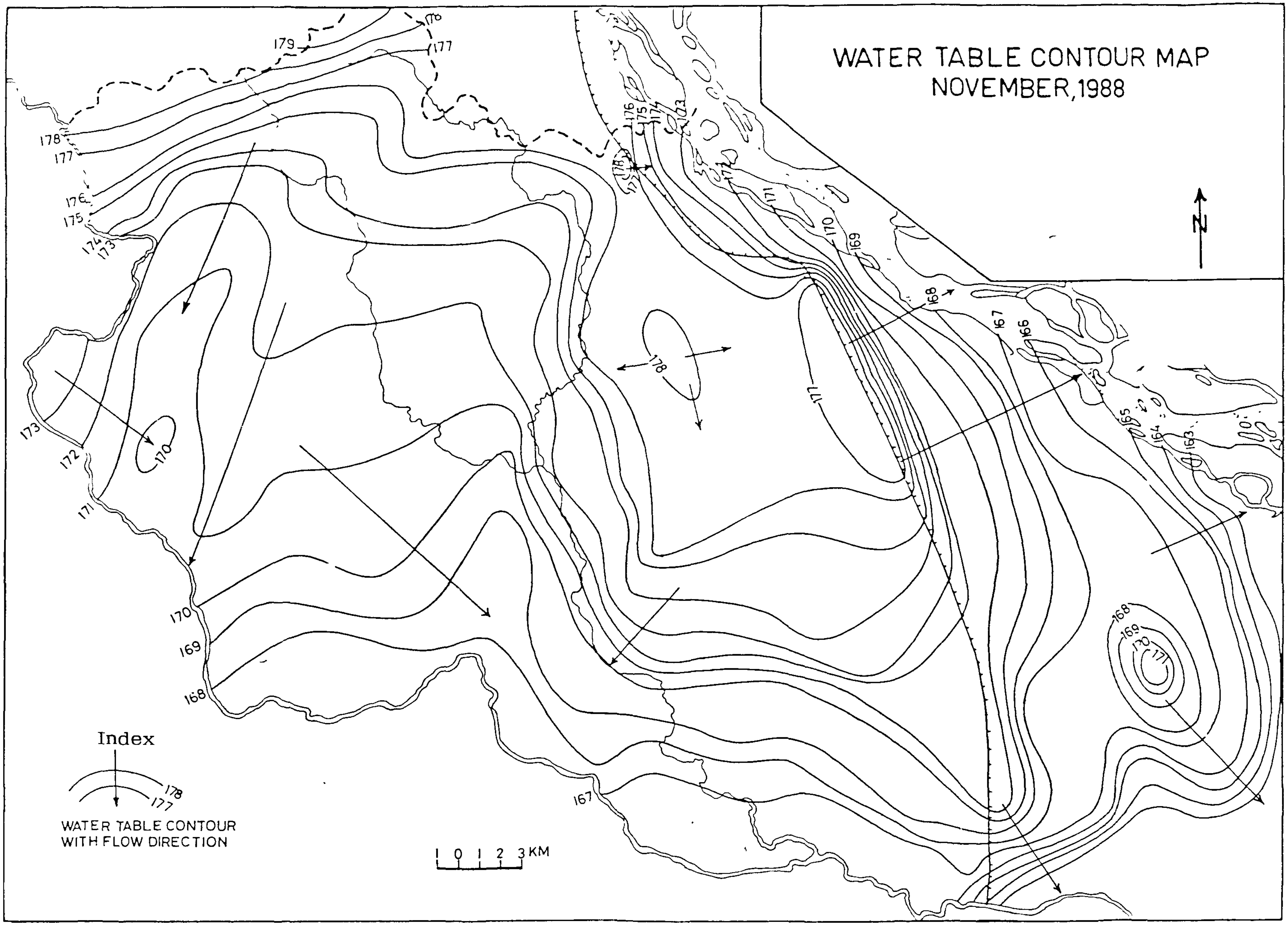
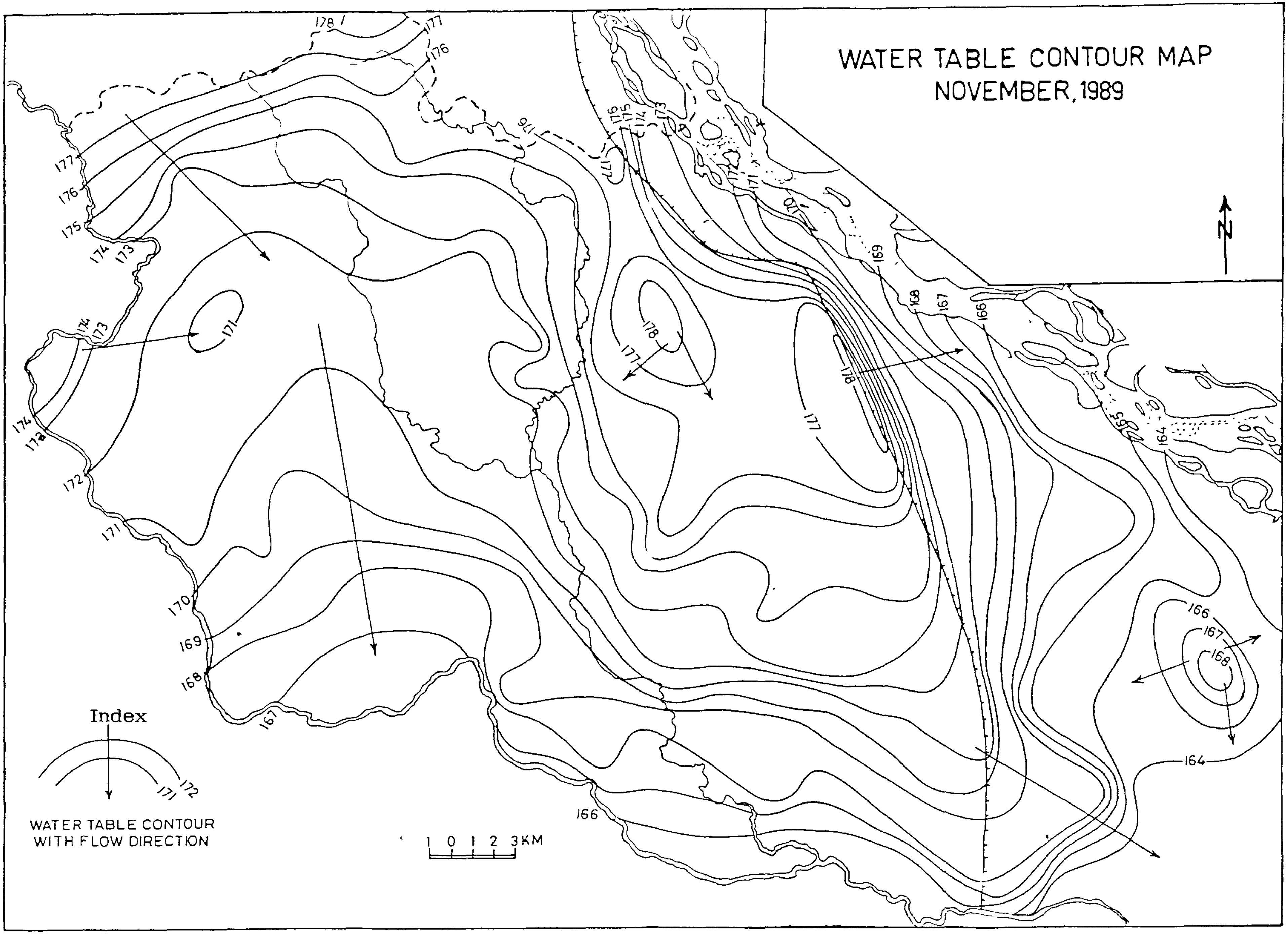

WATER TABLE CONTOUR MAP
NOVEMBER, 1988
N
179
178
177
176
175
174
173
172
171
170
169
168
167
166
165
164
163
Index
WATER TABLE CONTOUR
WITH FLOW DIRECTION
0 1 2 3 KM

FIG.30-b


WATER TABLE CONTOUR MAP
NOVEMBER, 1989
N
Index
WATER TABLE CONTOUR
WITH FLOW DIRECTION
1 0 1 2 3KM
178
177
176
175
174
173
172
171
170
169
168
167
166
165
164

imparts an influent character to the Kali river which was otherwise basically effluent in nature. This reversal of hydraulic gradient is the resultant of the excessive withdrawal of the groundwater in the area.

Post-Monsoon Water Table Contours

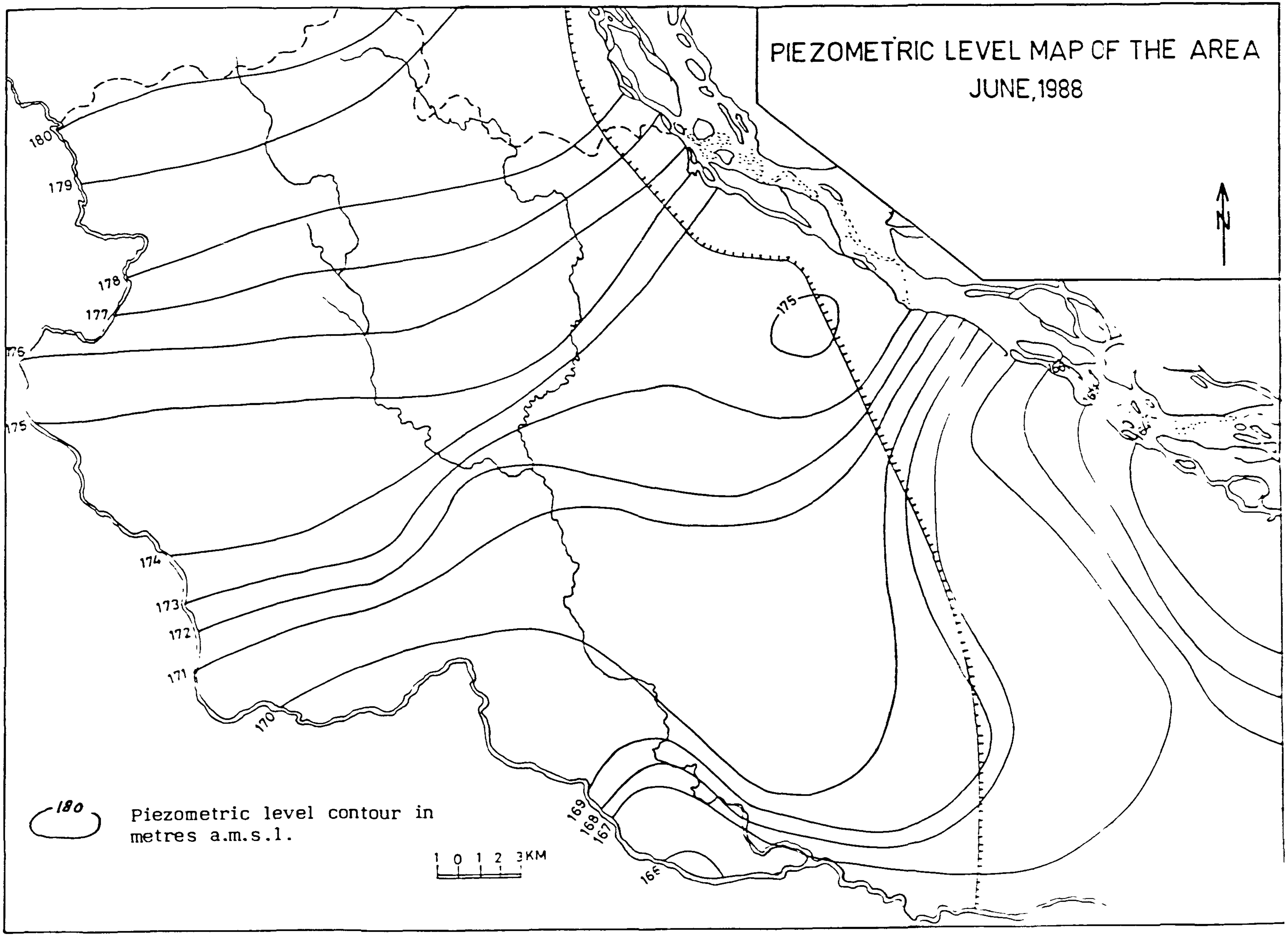
Map (Fig. 29b & 30b) shows the post-monsoon water table contours for the period 1988 & 1989 respectively. The 1989 post-monsoon water table contour values remain essentially the same because of low fluctuation in water table. But during 1988 due to high fluctuations in water level, contours are found some what displaced by higher contour values.

Piezometric Level Map

A piezometric level map (Fig. 31) has been prepared considering the piezometric head in tubewells. The map shows that pattern of piezometric level contours is almost similar to that of water table contour maps (Fig. 29 & 30) but in the north-eastern side the piezometric heads were higher than water table by about 2 m above mean sea level. Moreover, the piezometric level map shows gentle hydraulic gradient than water table contour map.

FIG.31

PIEZOMETRIC LEVEL MAP OF THE AREA
JUNE, 1988



Long Term Behavior of Water Levels

Hydrographs

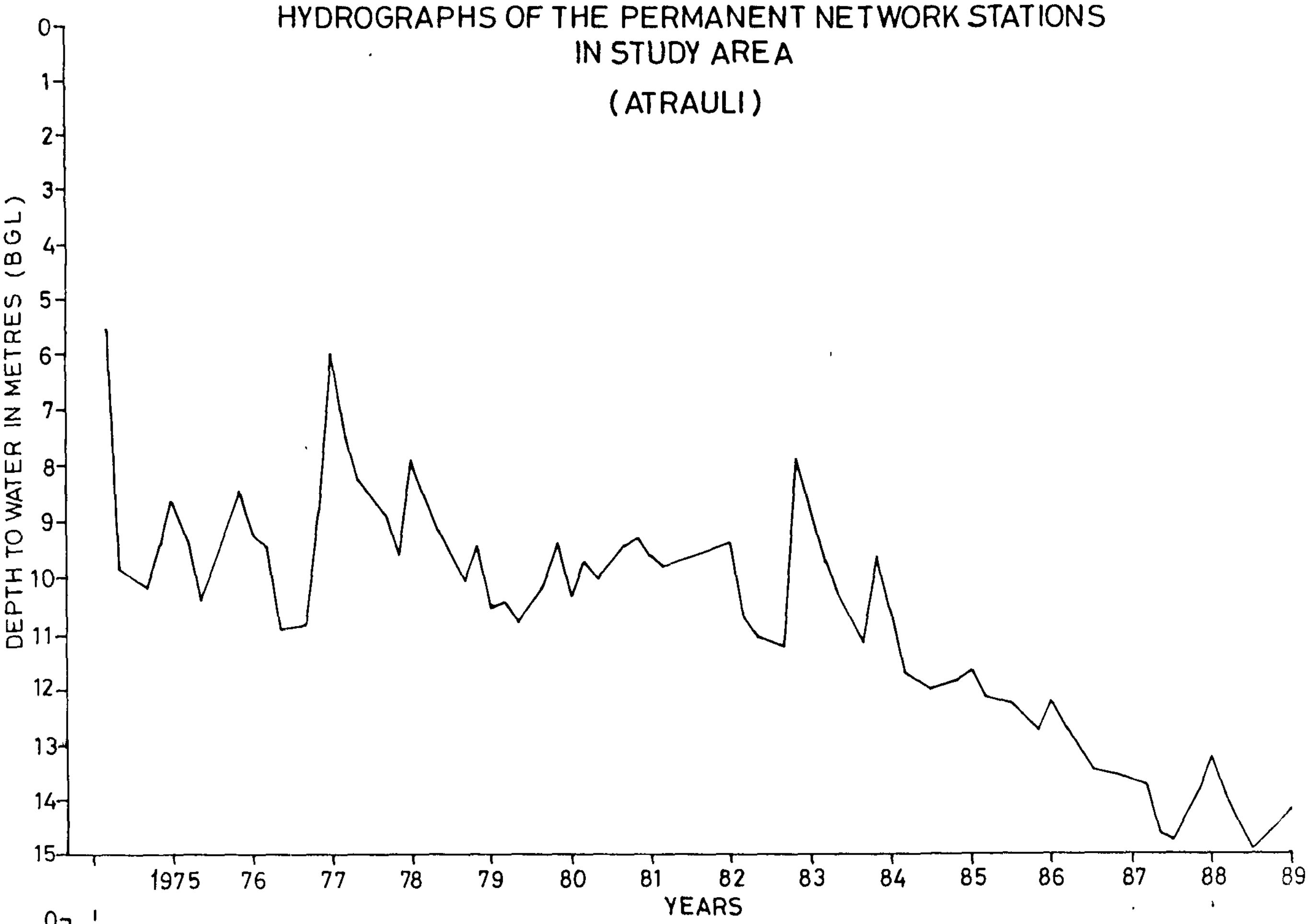
The water levels of the key observation wells in the area have been utilized for preparing continuous hydrographs of the well with a view to studying their behaviour with respect to time and space and their dependence on natural phenomenon. For this purpose eight hydrograph stations were chosen in different physiographic units and their water level data collected and plotted (Fig. 32 a & b). A perusal of hydrographs indicates that water level variation is cyclic and sinusoidal as a function of time and space. It is observed **that** water level start rising by the last week of June and **attains** shallowest level in November. From November onwards there is sharp decline in water level. From January onwards the recession in water level is slow indicating natural groundwater discharge through steady sub-surface outflow, in harmony with regional groundwater movement.

From the above discussion it will be seen that water level has rising and declining trends with respect to time and space a function which causes such rises in water level, that is input source (rainfall).

Further, it is seen from the hydrographs that there was progressive decline in water level in Nimi-Kali interfluves where as hydrographs falling in Ganga-Nim interfluves does not show

FIG.32-a

HYDROGRAPHS OF THE PERMANENT NETWORK STATIONS IN STUDY AREA



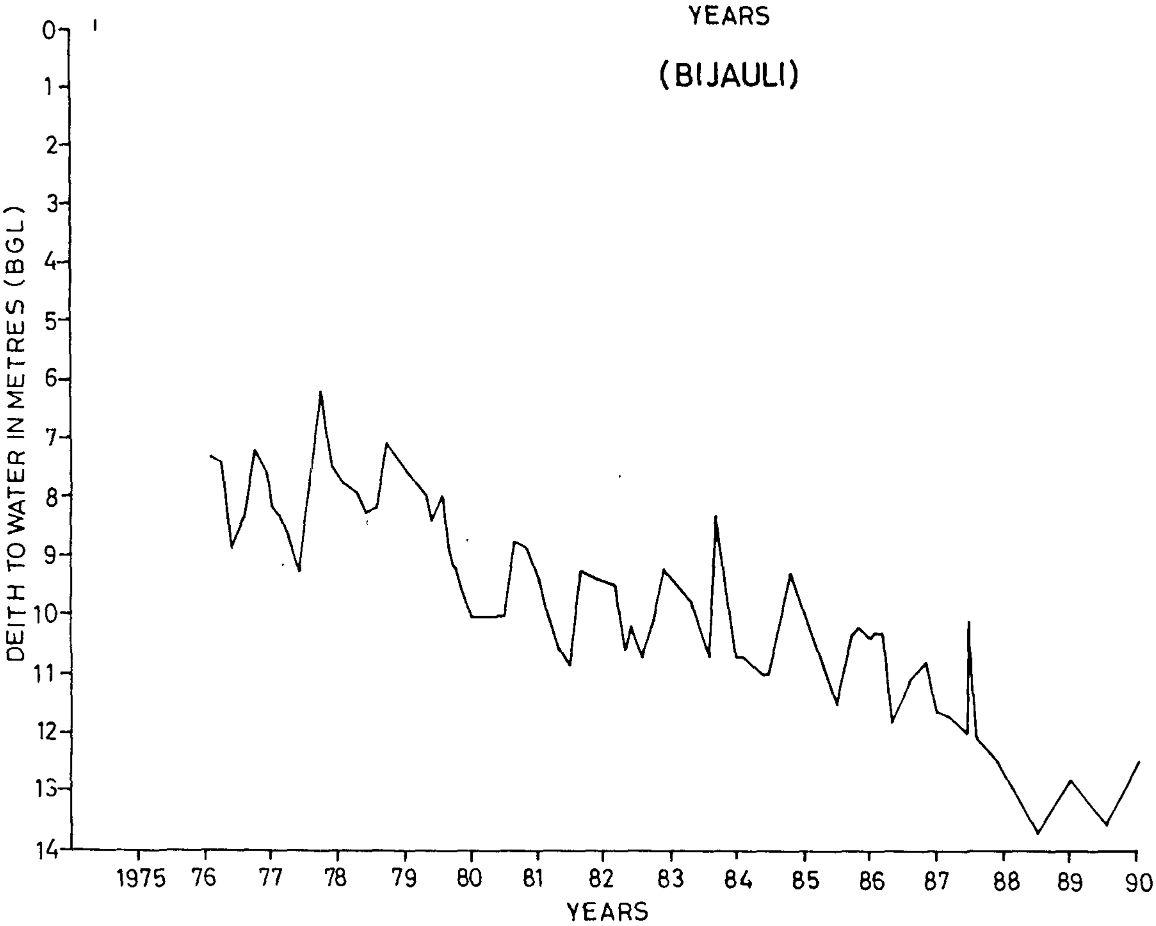
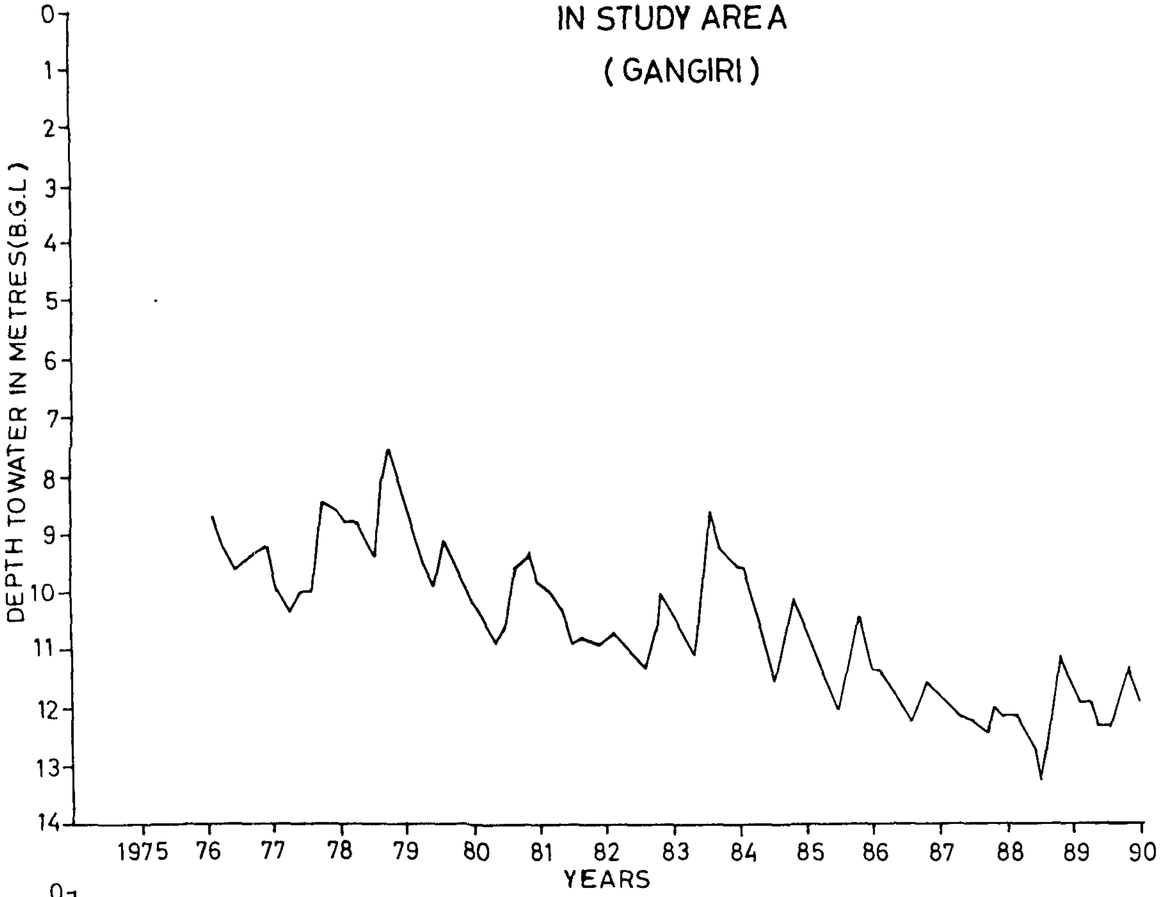


FIG:32-a

HYDROGRAPHS OF THE PERMANENT NETWORK STATIONS IN STUDY AREA



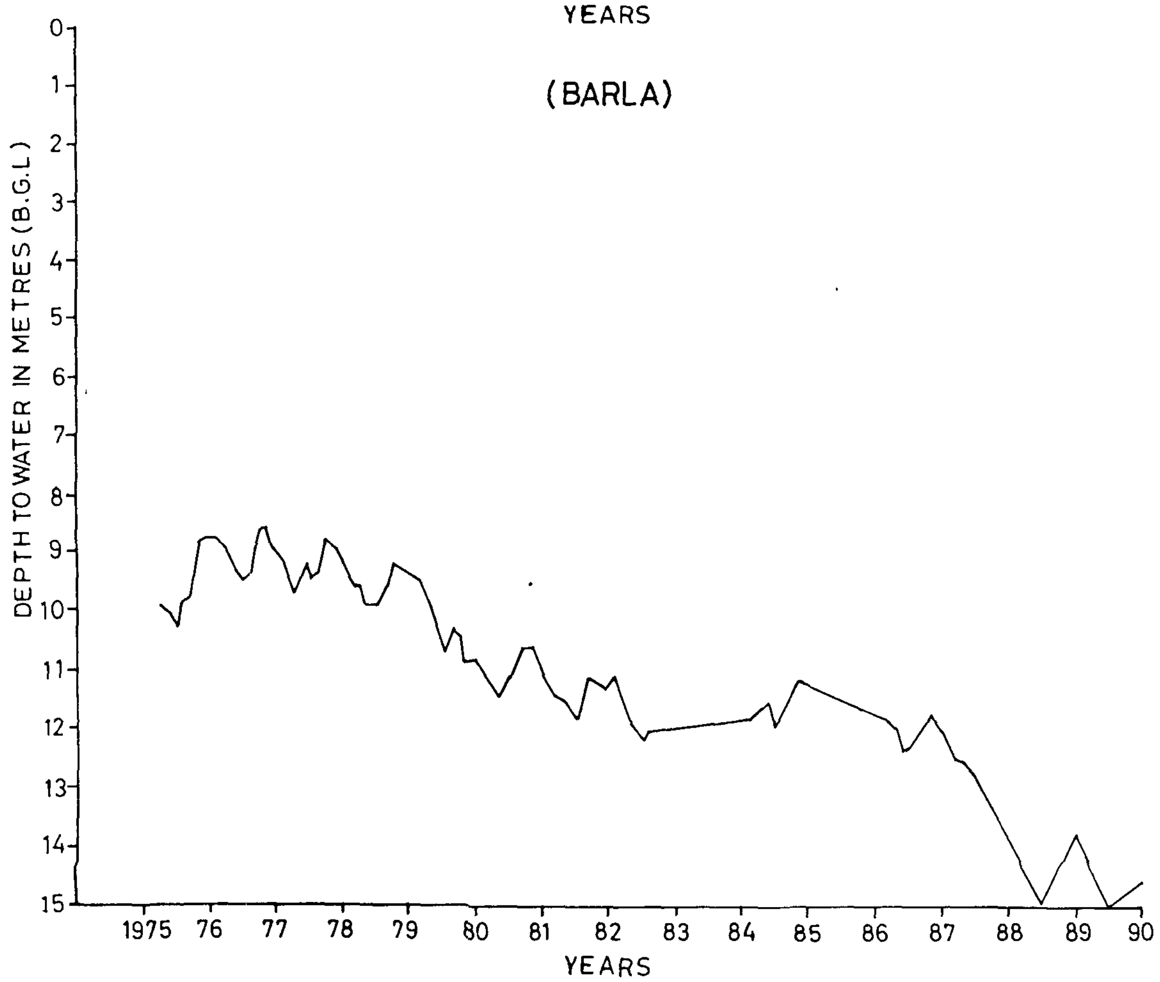


FIG.32-a

HYDROGRAPHS OF THE PERMANENT NETWORK STATIONS IN STUDY AREA (CHARRAH)

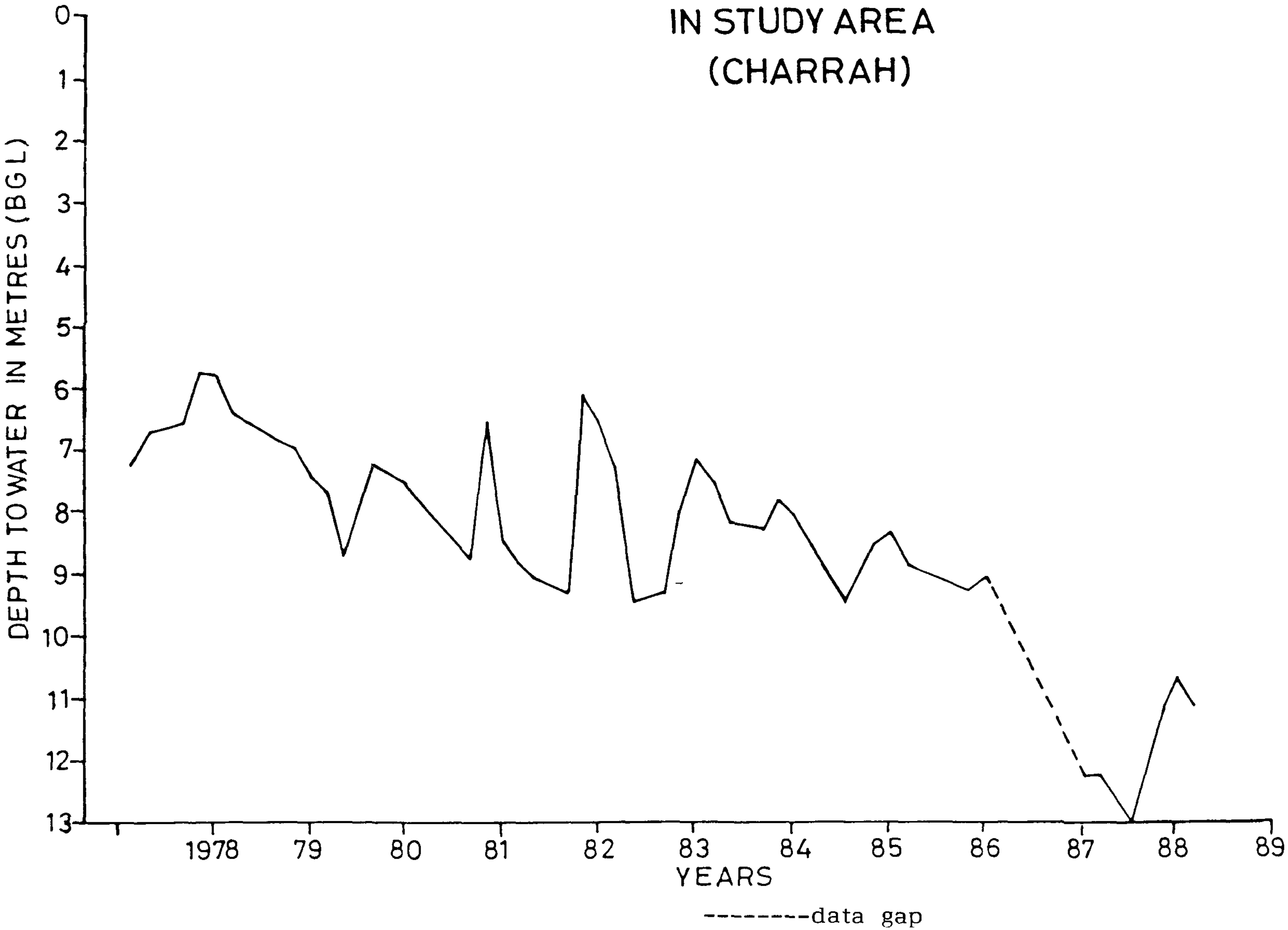
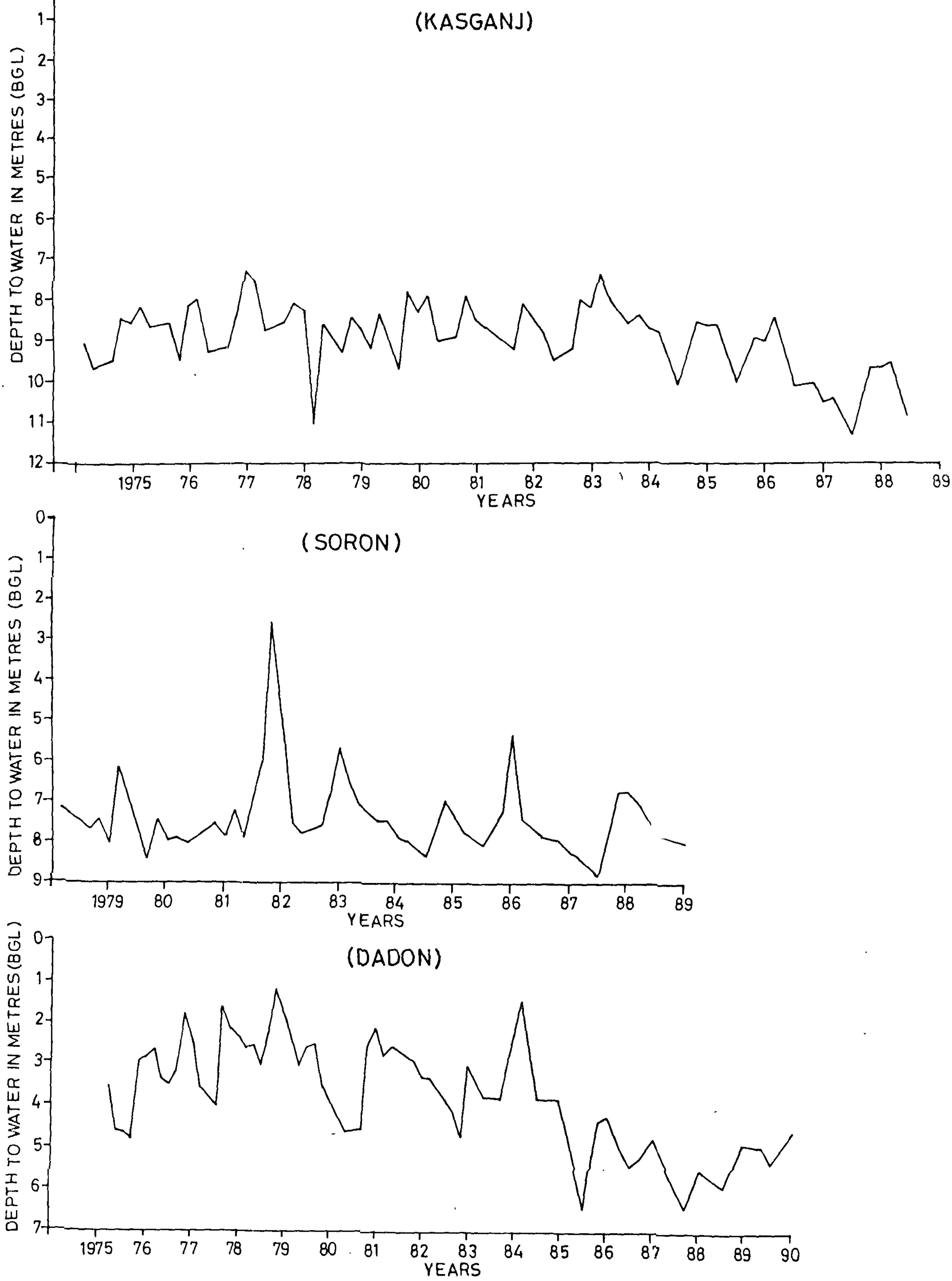


FIG.32-b

HYDROGRAPHS OF THE PERMANENT NETWORK STATIONS
IN STUDY AREA



any significant change in their behaviour. This is attributed to adequate recharge of the groundwater bodies through canal seepage in Ganga-Nim area and practically no recharge except rainfall in Nim-Kali interfluves.

Decline in Water Table

The study reveals that under the heavy demand of water in Nim-Kali interfluves, withdrawal of groundwater is much higher than the quantum of the average annual reccharge, which has induced declining trend (Fig. 32a). The analysis of four hydrograph stations data which fall in this physiographic unit shows that the water table in this unit has a declining trend and average rate of this decline is estimated as 0.34 m/year. This is alarming. The situation may aggravate in future due to increase in population, extensive agriculture practices and escalating industrialisation in this belt.

Correlation With Rainfall

In order to study the long range trend of water levels as a function of rainfall, the hydrographs of the wells situated at Atrauli, Charrah, Kasganj and Soron have been selected, so as to have an over all picture of the groundwater behaviour in the

FIG. 33-a

VARIATION IN AVERAGE WATERTABLE WITH MONTHLY RAINFALL
(ATRAULI)

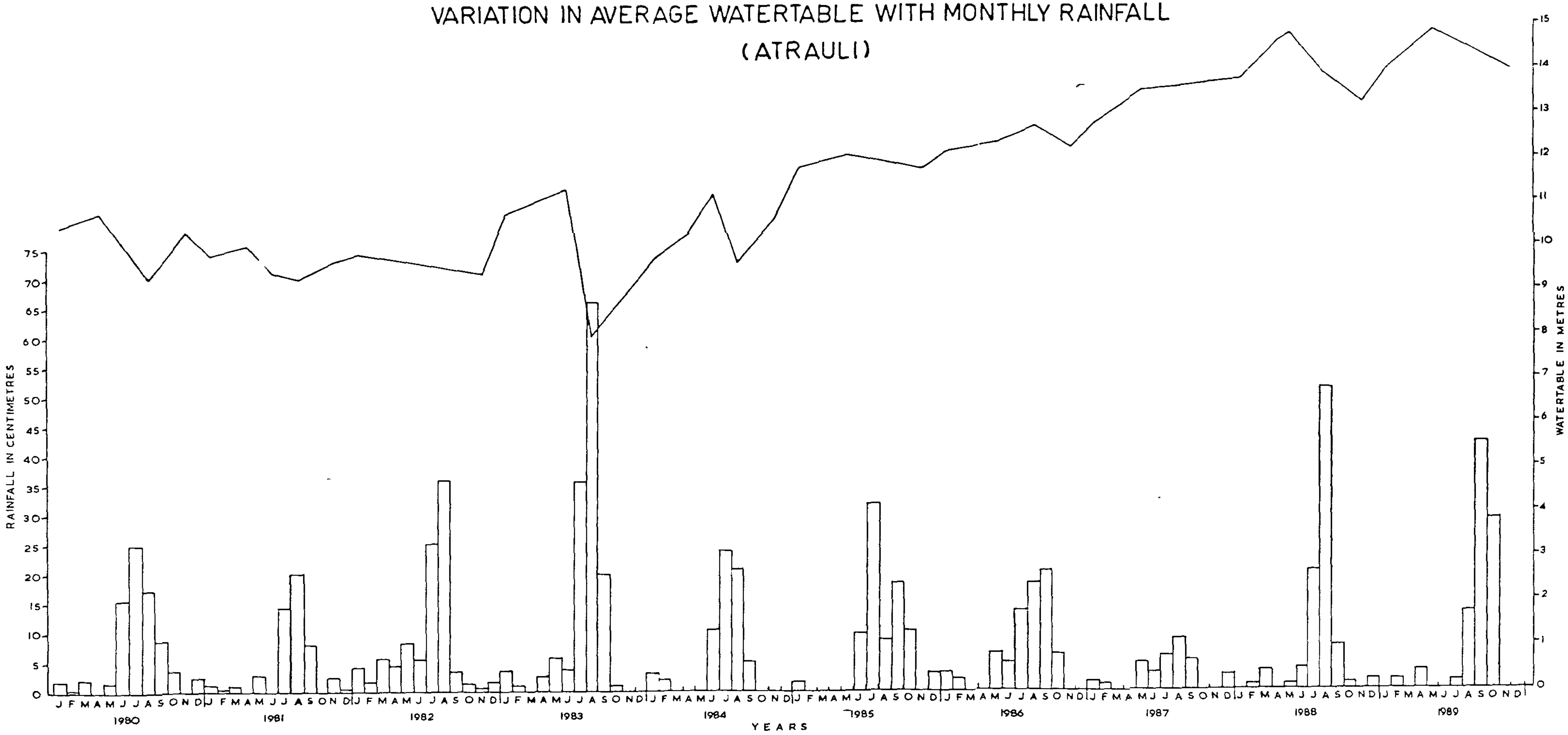


FIG 33-a

VARIATION IN AVERAGE WATERTABLE WITH MONTHLY RAINFALL (CHARRAH)

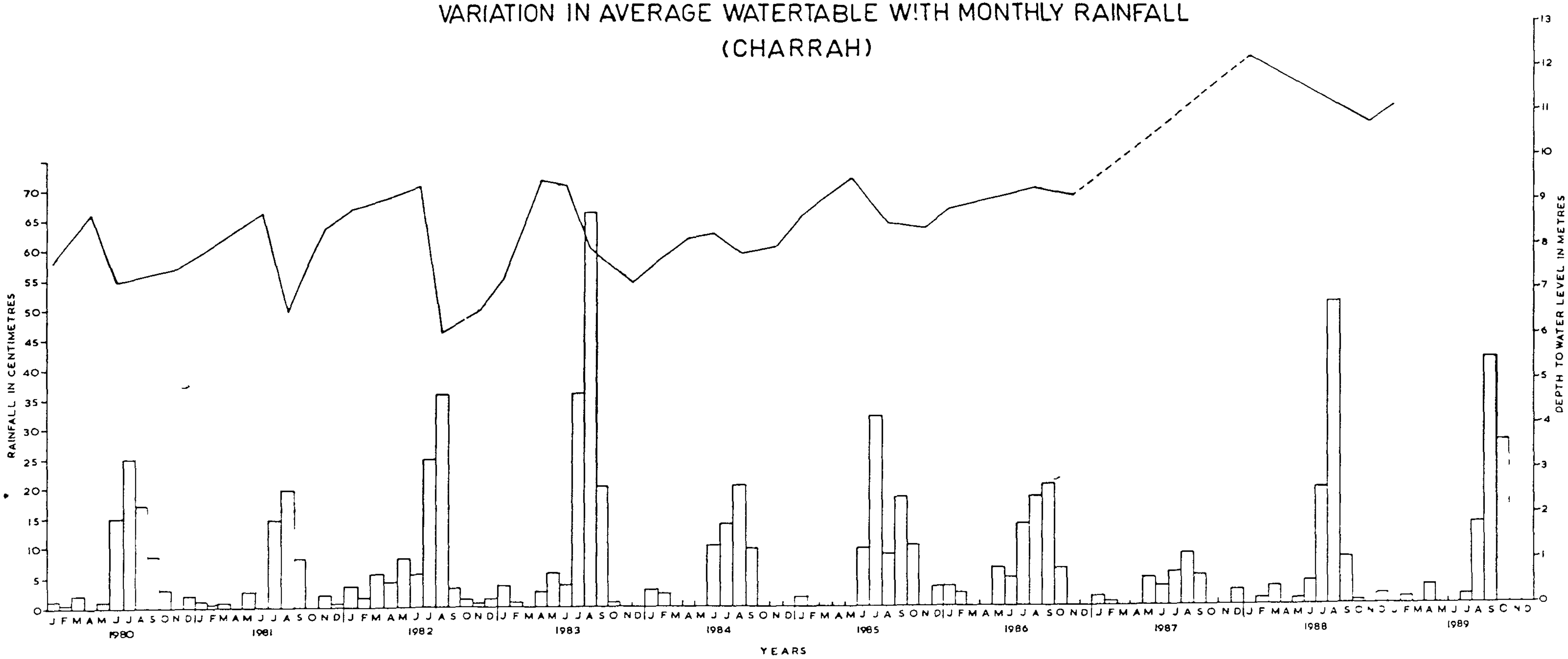


FIG.33-b

VARIATION IN AVERAGE WATERTABLE WITH MONTHLY RAINFALL
(KASGANJ)

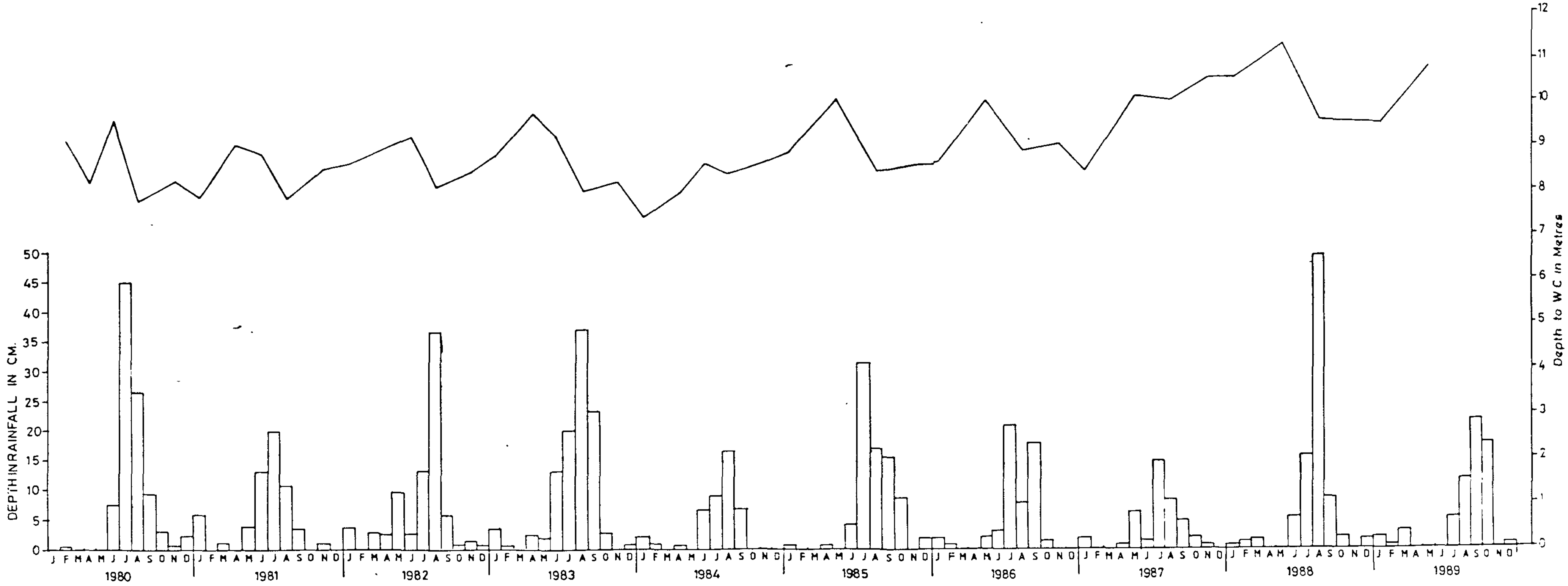
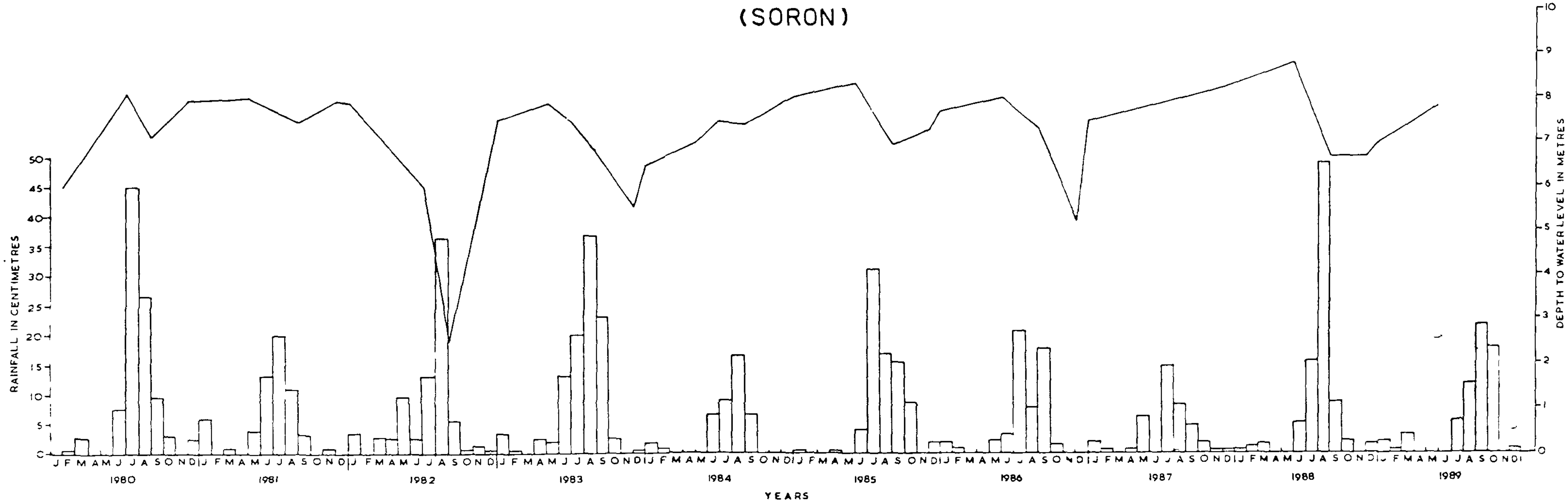


FIG. 33-b

VARIATION IN AVERAGE WATERTABLE WITH MONTHLY RAINFALL (SORON)



basin. The correlation of the groundwater levels with rainfall were made since 1988 to 1989 (Fig. 33a & 33b).

A critical study of hydrographs indicates that the response of water levels to rainfall and droughts is reasonably quick. The ascent of level is also greatly affected by the intensity and distribution of rainfall.

Iso-permeability Map

Logan (1964) reasoned that if a well is pumped for such a long period that the flow is in steady state, then an approximate estimation of the order of magnitude of the transmissivity can be made using the Theims formula for a confined aquifer which can be written as ;

$$T = \frac{2.3\ Q \log\ (rmax/rw)}{2\pi Smw} \qquad \text{------ ------ (1)}$$

where,

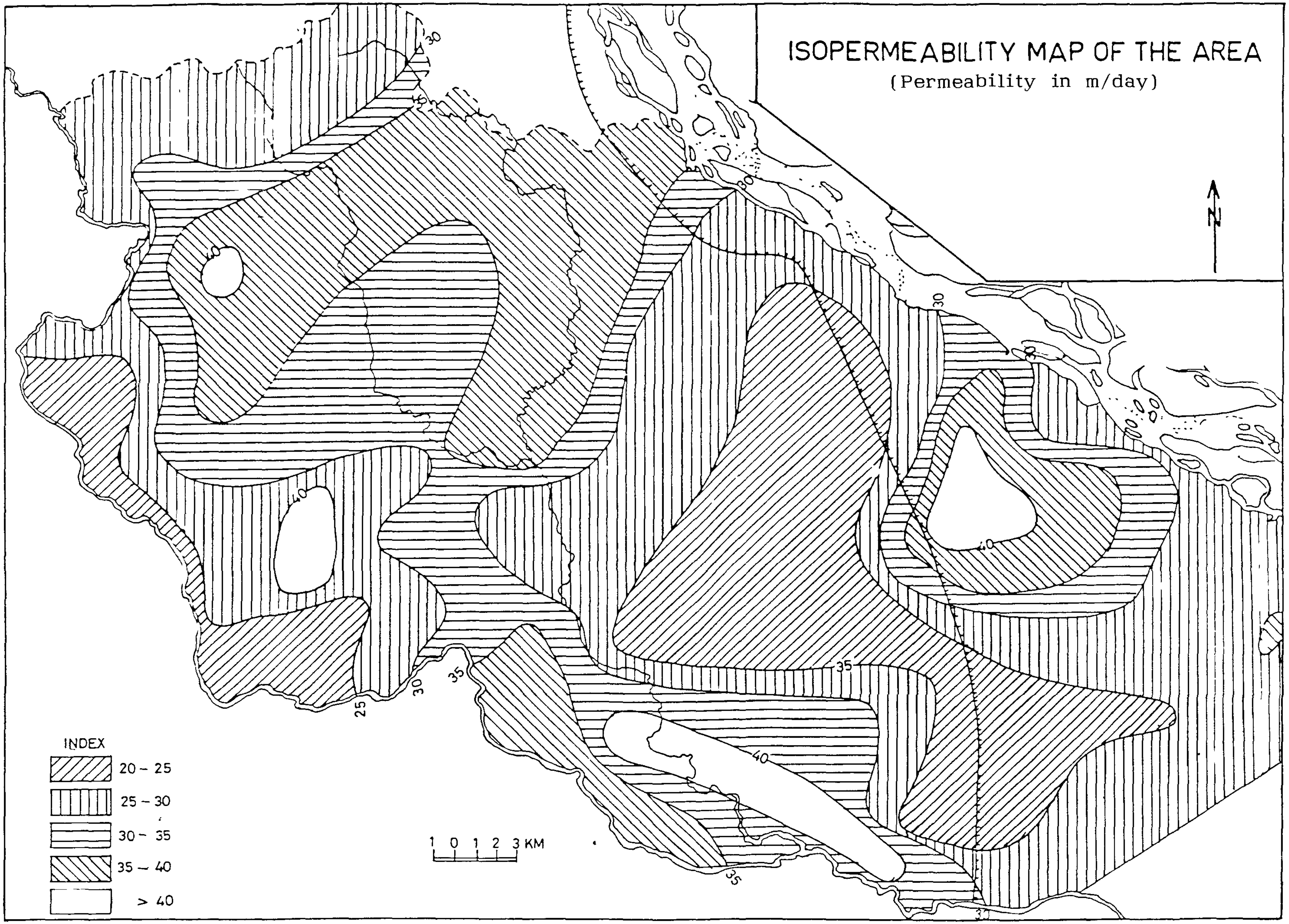
r = radius of pumped well in metres

r_{max} = radius of influence in metres

Smw = maximum drawdown in the pumped well in metres.

Logan, further stated that the accuracy of the calculation depends only on the accuracy of measurement of Smw (on which well losses may have substantial influence) and on the accuracy of the ratio rmax/rw. As rmax/rw cannot be accurately determined

FIG.34


ISOPERMEABILITY MAP OF THE AREA
(Permeability in m/day)
N
INDEX
20 – 25
25 – 30
30 – 35
35 – 40
> 40
1 0 1 2 3 KM
40
35
30
25

generally, Logan opined that although the variation in rmax and r_w may be substantial, the varriation in the logarthim of their ratio is much smaller. Hence, assuming average conditions of ratio, he suggested a value of 3.33, for log ratio which may be taken as rough approximation.

Substituting the value in the equation (1), we get the Logan's formula,

$$T = \frac{1.22\ Q}{S_{mw}} \qquad \text{----------} \ (2)$$

where, S_{mw} is the maximum draw-down in a pumped well.
According to Kruseman and de Rider (1970) Logan's formula in above form gives erroneous results of the order of 50% or more.

However, based on Logan's, an isopermeability map of the area was prepared (Fig. 34). For the purpose, specific capacity and drawdown data of various tubewells were collected and utilised for the determination of transmissivity and premeability by Logan's formula.

A perusal of the isopermeability maps of the area of investigation shows that there are six isopermeability zones viz. (1) < 25 (2) 25-30 (3) 30-35 (4) 30-40 (5) 40-45 and (6) more than 45.

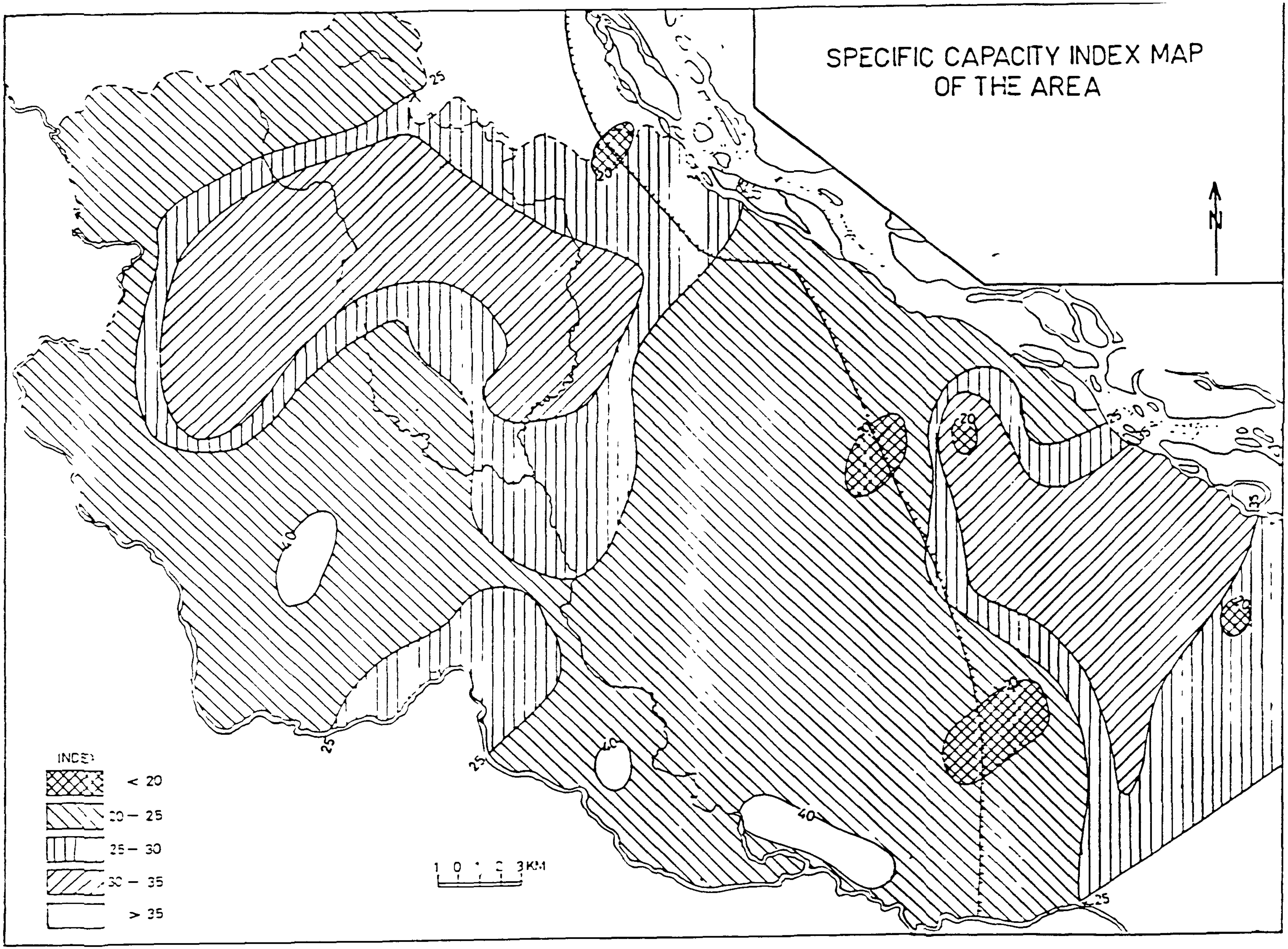
The permeability ranges between 25 to 30 m/day in the area lying close to the Kali river but gradually increases due east towards the Nim river where it ranges between 35 to 40 m/day with some local variations at places. In between the Nim-river and Lower Ganga canal, again the permeability decreases and there the values recorded show 25 m/day. Further, south the permeability values for the area lying between the lower Ganga canal and the Ganga river, values range between 25 to 30 m/day. Although the area lying between the Lower Ganga canal and the Nim shows a very high sand percent (60-80%) but the permeability values recorded are very low (25 m/day). Similar situation are observed in the area close to the Ganga river. This may possibly be attributed to the subtle variation in the grain size, sorting characteristics, and grain packing representing microscopic inhomogeneities that control porosity and permeability, and thus fluid flow characteristics.

Because of paucity of pumping test data analysis the value of T and K determined by Logan's formula could not be compared with the pumping test data except for few places only.

In Atrauli, the value of K obtained by Logan's formula is in close agreement with the values of K determined through pumping test data analysis. But at Paharipur the difference in the value is more than 50%. Thus the values obtained by Logan's method give only approximate picture.

Specific Capacity Index Map

The specific capacity, besides being an index of well productivity, serves also as a parameter of yielding and


SPECIFIC CAPACITY INDEX MAP
OF THE AREA
N
INDEX
< 20
20 — 25
25 — 30
30 — 35
> 35
1 0 1 2 3 KM
25
25
25
25
40
40
40
20
35

transmissive capacity of an aquifer (Karanth, 1987). The yielding capacity is denoted by an yield factor (or specific capacity index), which expresses the specific capacity of the well for the unit thickness of the aquifer tapped.

$$\text{Yield factor} = \frac{\text{Specific capacity}}{\text{Thickness of the aquifer}}$$

Based on this formula the specific capacity index was determined from the available data of tubewells of the area, and the specific capacity index map was prepared (Fig. 35).

A perusal of the map shows that there are following yield factor zones.

(1) < 20 (2) 20-25 (3) 25-30 (4) 30-40 m/day. The yield factor ranges between 20 to 25 m/day towards Kali river. The area surrounding Atrauli town shows moderately high value of specific capcity index which ranges between 30 to 35 m/day. On the eastern upland lying between the lower and upper Ganga canals, the value of specific capacity index is < 20 m/day. Further in the tract between the lower Ganga canal and the active channel of Ganga, it ranges between 25 to 30 m/day. However, the average value of the specific capacity for the entire basin is recorded as 25 m/day.

Pumping Test and Data Analysis

Groundwater resource development and management concern with the sustained yields of wells and aquifers, the interference between wells and well field, the interrelation between surface and groundwater and the quality of groundwater. As the use of groundwater resources requires that pumping be related to water level changes with reference to time and space. The hydrogeologic properties and dimensions of aquifers and aquitards and the boundaries of aquifers are of utmost importance in relating cause and effect. An answer to most of the above question lies in pumping test and data analysis. One of the fundamental aspects of groundwater resources investigation is the determination of the aquifer characteristics of permeability (K) and storage coefficient (S). These characteristics are important in determining the natural flow of water through an aquifer and its response to withdrawals. Generally the determination of aquifer parameter such as coefficient of permeability and storitivity are made on the basis of data obtained from pumping tests of wells. For the proper evaluation of groundwater resource it is an essential prerequisite that pumping test are conducted so that these parameter can reliably assessed. Moreover, such data are also required for proper well spacing and scientific development of this valuable resource.

Method of Analysis

The pumping data test were analysed by methods which were considered most appropriate to the field conditions. The method of analysis of drawdown data in different types of aquifer are out lined below.

Confined Aquifer

The only solution available for radial flow problems prior to 1935 were steady-state formulae such as that of Dupuit-Theim, which frequently required a lengthy duration of pumping to satisfy the conditions governing the equation.

Thies(1935) introduced the first non-steady state solution which took into account the related parameters of time and aquifer storage. The equation which he derived specifically for confined aquifers has the following form:

$$s = \frac{Q}{4\pi T} \int_u^\infty \frac{e^{-u} du}{u}$$

or $$s = \left[\frac{Q}{4\pi T}\right] w(u) \qquad \text{----------} \ (1)$$

or $$T = \frac{Q}{4\pi s} w(u) \qquad \text{----------} \ (2)$$

where,

$$U = \frac{r^2 s}{4Tt}$$

or $$S = \frac{4\ Tt\ u}{r^2} \qquad \text{----------} \ (3)$$

where,

r = distance in metres of an observation well from the pumped well

s = the drawdown in metres in an observation well located at a distance r from the pumped well

Q = the constant well discharge in m^3/day

S = storativity

T = transmissivity in m^2/day

t = the time since pumping started

w(u) = well function of u

For the use of Thesis's method following assumptions and limiting conditions should be satisfied.

1. The aquifer is homogeneous, isotropic and of uniform thickness and infinite areal extent
2. Before pumping the peizometric surface is horizontal
3. The well is pumped at constant discharge rate
4. The pumped well penetrates the entire thickness aquifer, and flow is everywhere horizontal within the aquifer to the pumped well
5. The well diameter is infinitesimal so that the storage within the well can be neglected
6. Water removed from storage is discharged instantaneously with decline of head.

For calculation of aquifer parameters, standard technique of matching field data curves (t vs s) with Thesis type curves (1/u vs W(u), choosing match point and substituting their coordinate values in the equations mentioned, are used.

Jacob Method

Cooper and Jacob (1946) suggested a simplification of Theis equation (1) which dispenses with the need for type curves by utilizing a semilogarithmic plot for those field data where $U < 0.02$, which beyond the first log cycle of time usually gives a straight line relationship.

Jacob has shown that for small values of U ($U \leq 0.01$), i.e. where r is small and t is large Eq. $S = \frac{Q}{4\pi T} w(u)$ can be simplified and expressed as

$$s = \frac{2.30Q}{4\pi T} \log \frac{2.25\ Tt}{r^2 s} \qquad \text{---------- (3)}$$

Thus, a plot of drawdown, 's', versus logarithm of time, t, forms a straight line. Equation (3) can further be solved to give;

$$S = \frac{2.25\ T\ t_0}{r^2} \qquad \text{---------- (4)}$$

and

$$T = \frac{2.30\ Q}{4\ \pi \Delta s} \qquad \text{---------- (5)}$$

where,

to = time in days corresponding to interception of straight line with axis, where s = 0

Δs = slope of straight line in metres.

By plotting time versus drawdown on a semi-logarithmic paper (time on log scale) a straight line is fitted by discretion.

The slope of straight line and its intercept on time axis, s = 0 are subtituted in equation (4) and (5) for determination of T and S values.

Boulton's Method

Boulton (1963) assumes that the effective co-efficient of an unconfined aquifer is

$$S_A + S_Y = N S_A \qquad \text{----------} (1)$$

or

$$N = 1 + \frac{SY}{SA} \qquad \text{----------} (2)$$

where,

N = a factor

SA = early time coefficient of storage

SY = specific yield.

The general flow equation for an unconfined aquifer with delayed yield, in analogy to the Theis equation is expressed as,

$$s = \frac{Q}{4 \pi T} \; w\,(U_{AY}, \; r/B) \qquad \text{----------} (3)$$

where,

$w(U_{AY}, r/B)$ may be called the well function of Boulton. Under early time conditions, equation (3) reduces to

$$s = \frac{Q}{4 \pi T} \; w\,(U_A, \; r/B) \qquad \text{----------} (4)$$

where,

$$U_A = \frac{r^2 S_A}{4\ Tt}\ w\ (U_A, r/B)$$

or

$$S_A = \frac{4T\ t\ U_A}{r^2} \qquad \text{----------} \ (5)$$

Under later time conditions equation (3) reduces to,

$$s = \frac{Q}{4\pi T}\ w\ (U_Y,\ r/B) \qquad \text{----------} \ (6)$$

where

$$U_Y = \frac{r^2\ S_Y}{4\ Tt}$$

or

$$S_Y = \frac{4\ Tt\ U_Y}{r^2} \qquad \text{----------} \ (7)$$

Also,

$$U_Y = U_A\ (N-1) \qquad \text{----------} \ (8)$$

The above mentioned formulae are valid only when N tends to infinity. In practice this means $N > 100$. Boulton's method is not applicable when $N < 10$. However, it may be applied when $10 < N < 100$. If N tends to infinity, the middle part of the second segment of time - drawdown plot approaches a horizontal asymptote given by

$$W\ (U_{AY},\ r/B) = 2\ K_0\ (r/B) \qquad \text{----------} \ (9)$$

or

$$S = \frac{Q}{2\pi T}\ K_0\ (r/B) \qquad \text{----------} \ (10)$$

K_0 (r/B) is the modified Bessel function of the second kind and zero order. The element B, may be called the drainage factor, it is defined as,

$$B = \frac{T}{\alpha S_Y}$$

and is expressed in metre $1/\alpha$ is called Boulton's "delay index". It is expressed in days and is used in combination with Boulton's delay index curve to determine the time, twt, beyond which the delayed yield ceased to affect the drawdown.

Assumptions of Boulton's Method

a. The aquifer is unconfined and displays delayed yield phenomenon
b. The flow to the well is in an unsteady state
c. The storage in the well is negligible.

The data plot of time versus drawdown is initially matched with Boulton's type - "A" curves. The match point co-ordinates are utilised in equation (4) and (5) to calculate T and S_A. The data plot is horizontally slided to obtain another match point with Boulton's type "Y" curves, holding r/B values the same as in previous case.

The co-ordinates of second match point are used in equations (6) and (7) to compute T and S_Y.

Knowing r/B and r, B is computed knowing B, S_Y and T. α is computed with equation $B = \frac{T}{\alpha S_Y}$. Then from Boulton's index curve of twt vs r/B, the value of twt is read and knowing α twt is computed, where twt represents the time beyond which the "type" curve merges with Theis type curve.

Results of Pump Tests

Pumping tests were conducted in couple of tubewells and data were collected to determine the aquifer parameters.

Before the present investigations various agencies had undertaken hydrogeological investigations of the study area for different purposes.

As part of present investigation, efforts were made to collect aquifer parameter data.

The erstwhile exploratory tubewell organisation now called as the Central Groundwater Board carried out exploratory drilling in Atrauli area during early sixties. During the investigation, short duration pump tests were conducted with or without observation wells by hydrogeologists at the site. The details of pump test results are summarised as below :

Site/Tubewell No.	Aquifer Parameters	
144 (Near Bhojpur)	T = 1761.05 m^2/day	Theis Recovery
158 (Lohgarh)	T = 636.48 m^2/day	" "
	Observation well-I	Observation -II
154 (Near Rasaini)	T = 2327 m^2/day	T = 2502 m^2/day
	S = 2.6 x 10^{-2}	S = 3.17 x 10^{-3}
161 (Near Bidhari Kalan)	T = 1599 m^2/day	T = 1405 m^2/day
	S = 3.9 x 10^{-2}	S = 3.21 x 10^{-3}

Besides E.T.O., aquifer performance test was conducted at Tikta village by Rao et al. (1965). They reported the value of transmissivity as 914.55 m^2/day and specific yield value 8.75%.

Dutt (1969) conducted a short duration aquifer performance test in Atrauli area without observation well and analysed the data by Theis recovery method. Dutt determined the value of T = 576 m^2/day and K = 22.2 m/day

Raja et al. (1989) made specific yield estimation at Chharra village using radioactive tracer techniques. Simultaneously he also carried pump test and grain size analysis to compare the results.

The values of aquifer parameters determined by Raja et al. (1989), are tubalated as below :

Table 9a : Results of specific yield by radioactive tracer technique.

Location	Discharge	Time of arrival of peak days	Aquifer-thickness	Distance between P.W.and O.W.well	Specific yield
Charra	1130 m^3/day	1.5	16.50 m	20 m	8.18%

Table 9b : Results of specific yield by Pump Test Method (Boulton's approach).

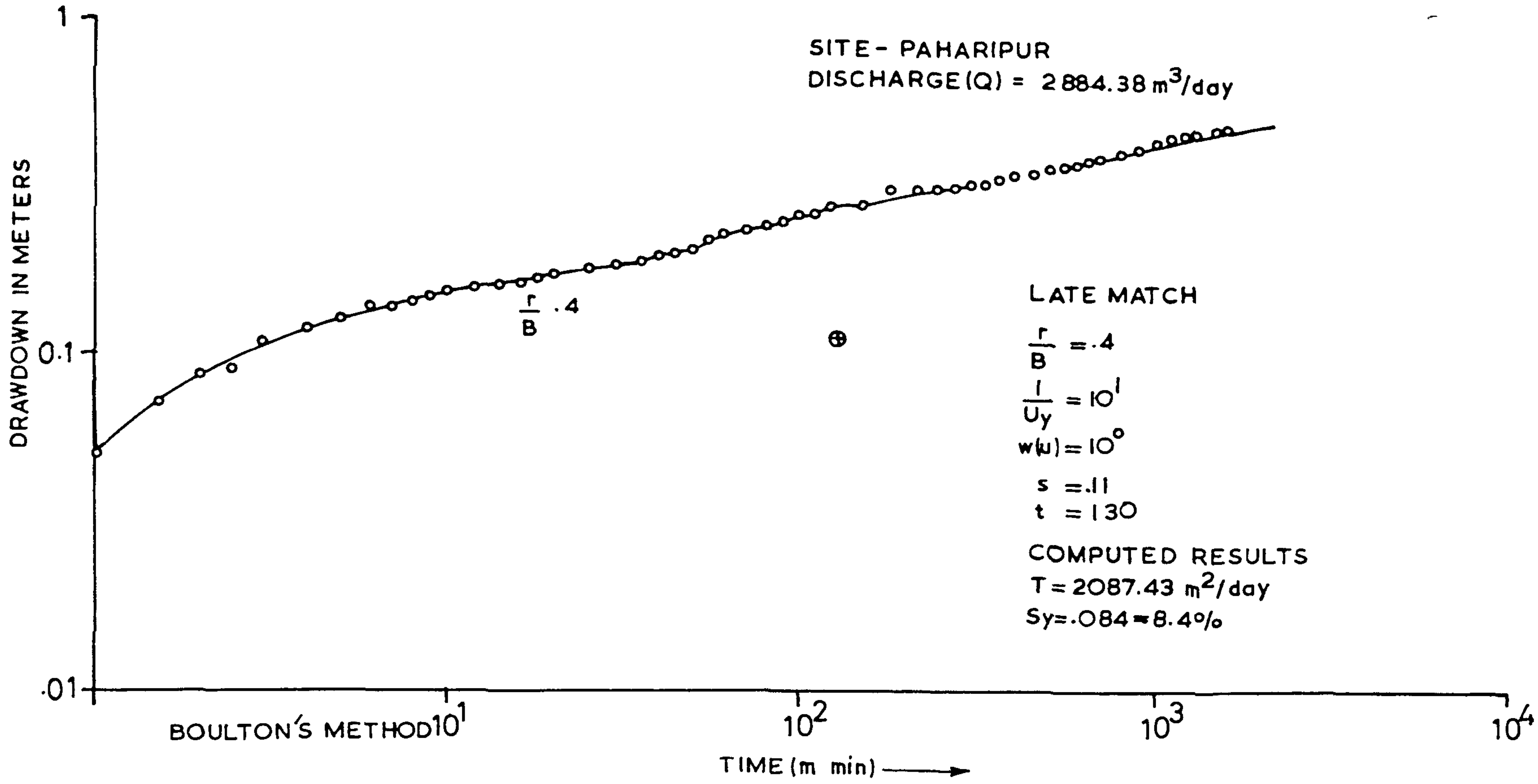
Location	Boulton's Constant $W(U_Y, r/B)$	$1/U_Y$	r/B	Drawdown (s) metre	Time (t)	S_Y	T m^2/day
Charra	5.6	100	.1	.52	.7639	7.4	968.89

Table 9c : Results of specific yield by grain size

Location	% of Grain size						
	Gravel	Course	Medium	Fine	Silt	Clay	S_Y%
Charra	2.0	8.0	48.0	5.0	15.0	22.0	10.00

FIG.36-a

TIME VS DRAWDOWN CURVE



The results obtained through radioactive tracer technique are almost matching with the pumping test and data analysis results. However, the values of specific yield obtained by the grain size analysis slightly differ with that of the pumping test and radio active tracer techniques.

Aquifer Performance Test

The aquifer performance tests were conducted at Paharipur and Danpur villages respectively. The site at Danpur is about 40 km north of Paharipur village. The data of these pump tests were analysed and the various aquifer parameters were determined which are tabulated as under :

Summary of Observations

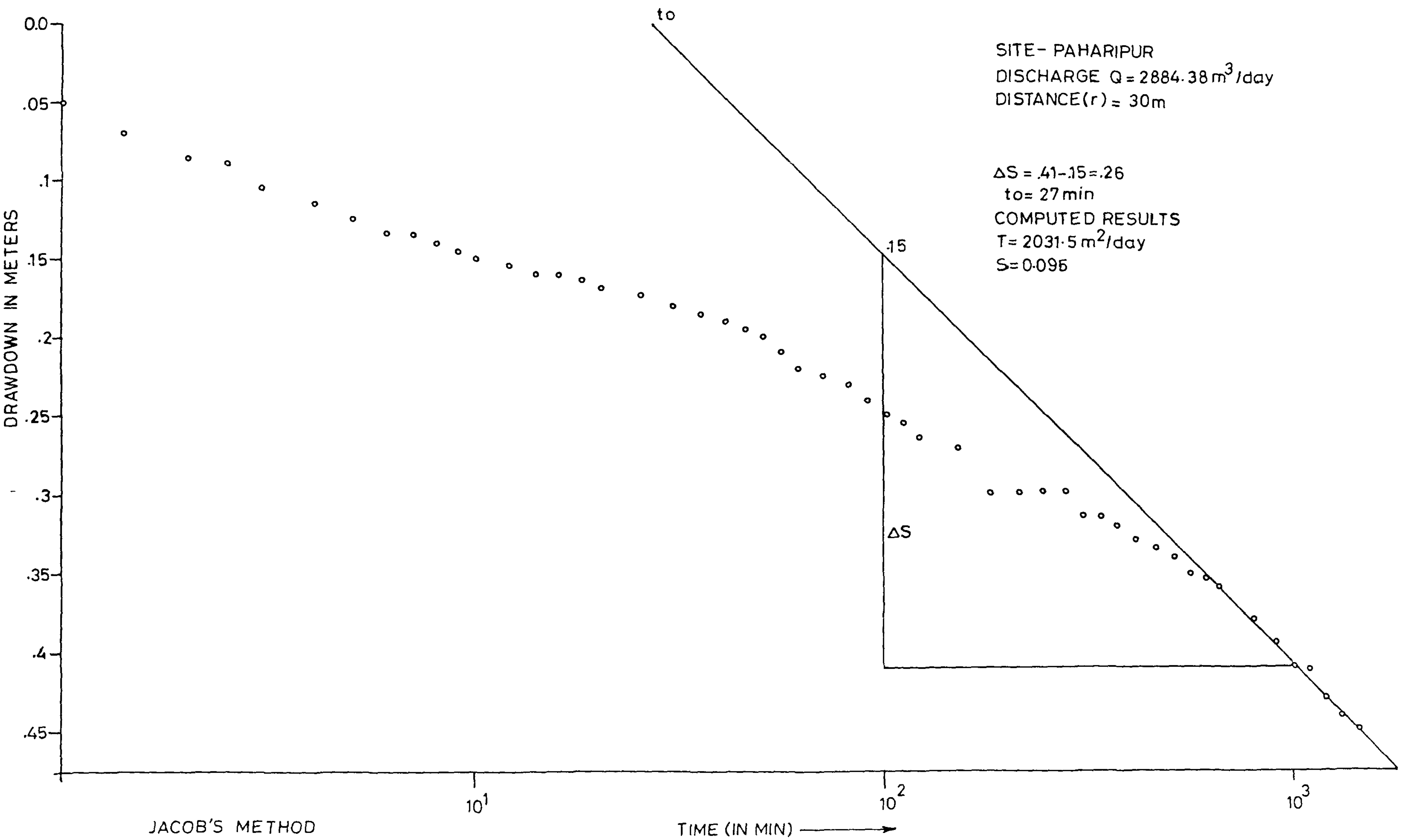
Site ---------------- Paharipur

District ------------ Aligarh

Duration of pumping	---------- 1605 minutes
Discharge	---------- 2884.38 m^3/day
Saturated thickness tapped	---------- 28.26 metres
Static water level in Main well	---------- 7.36 metres
Observation well	---------- 6.98 metres
Distance of the observation well from the pumping well.	---------- 30 metres

TIME VS DROWNOWN CURVE

FIG.36-b



Analysis of Data

The time drawdown field data curve resembles the typical "time-drawdown" curve for an unconfined aquifer with delayed yield and suggest unsteady state flow conditions at the end of pumping.

Under the prevailing flow conditions, Jacob (t vs s) and Boulton's methods of analysis were selectively used for the determination of aquifer parameters (36a & 36b).

Evaluation of Pumping Test Data Analysis Results

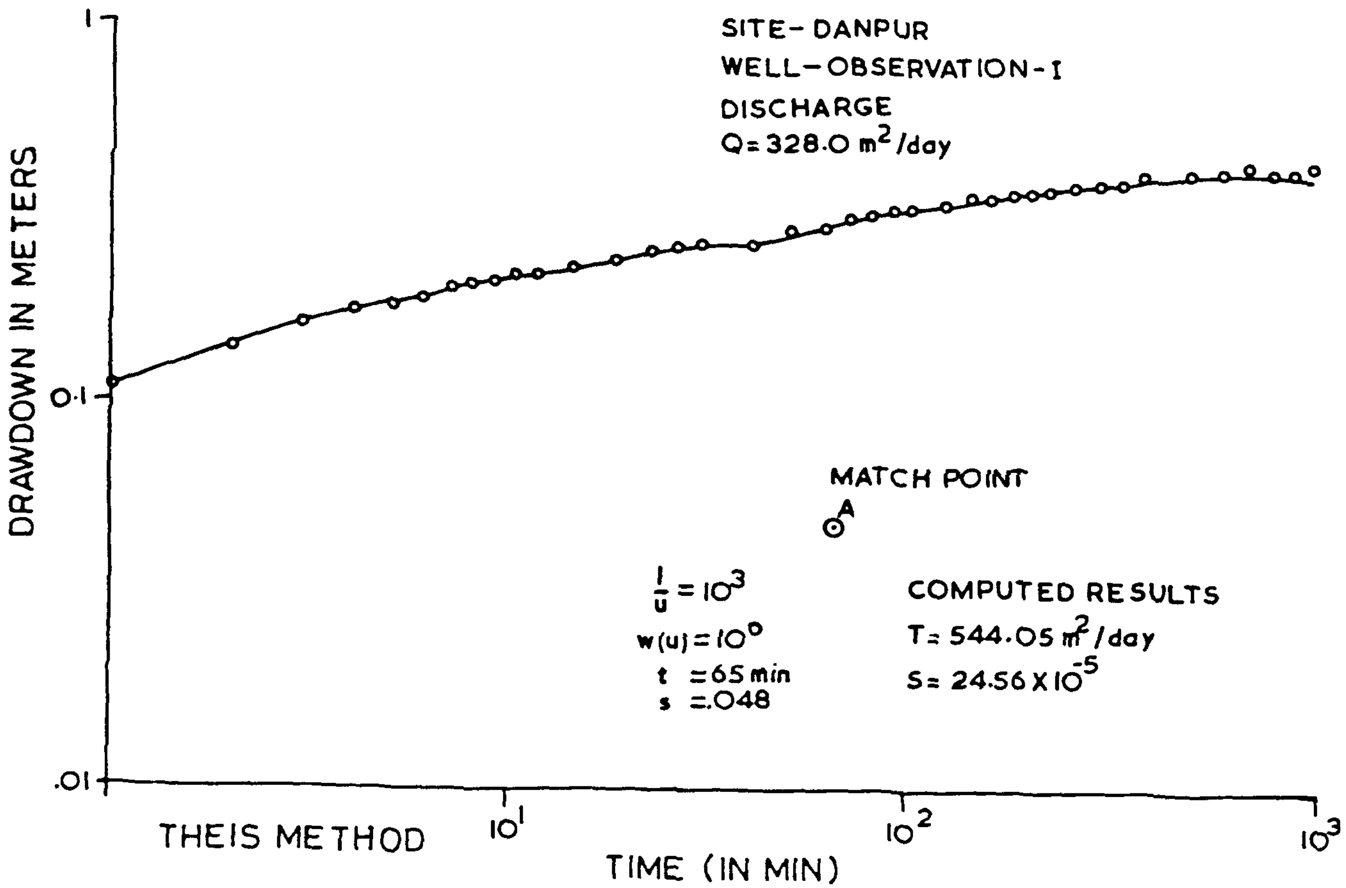
The aquifer parameter evaluated are tabulated as below:

Method of Plot	Data used	Value of T m^2/day	S_Y	K
Jacob (t V_s s)	obs.well	2031.5	0.095	71.88
Boulton's method	obs.well	2087.7	0.084	73.87

The time-drawdown curve of Paharipur test well suggests development of second and third stages only. The first stage is indicative of confined condition as is seen to have not developed. Consequently the third segment data have been analysed by Jacob's

FIG.37-a

TIME VS DRAWDOWN CURVE



method for the evaluation of T and S_Y. Data have also been analysed by Boulton's method which yield matching results for the late match. The initial data could not be analysed by Boulton's method due to non-development of first segment of time-drawdown curve.

In view of foregoing point an average of the values obtained by Jacob and Boulton's method are tabulated as under.

(a)	Transmissivity	---------- 2059.6 m^2/day
(b)	Specific yield	---------- 8.95
(c)	Hydraulic conductivity	---------- 72.88 m/day

Aquifer Test at Danpur

1.	Name of site	---------- Danpur
2.	Discharge maintained	---------- 328 m^3/day
3.	Duration of pumping	---------- 1220 minutes

Distance between pumped well and observation wells :

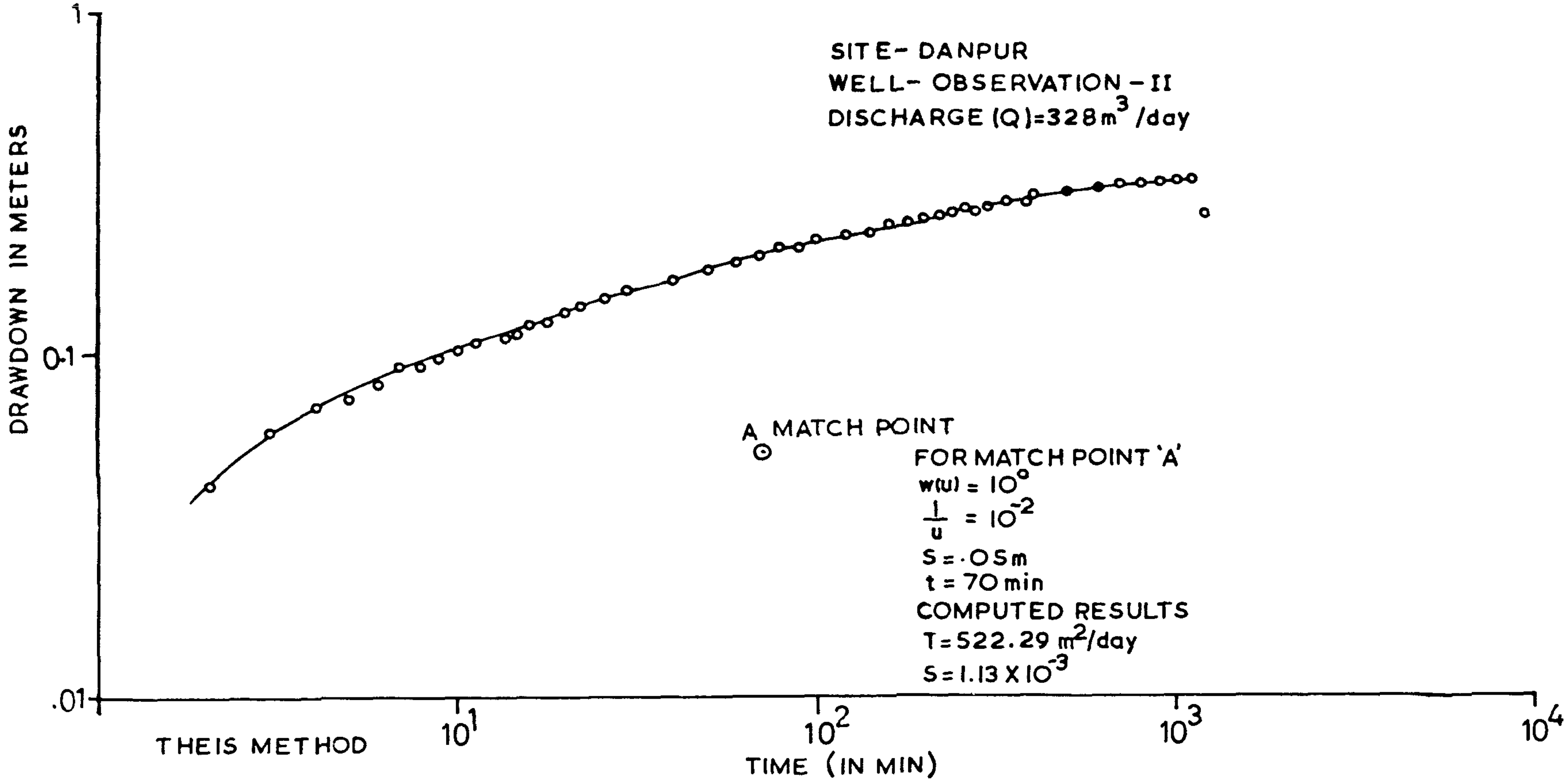
(i)	O.W. I	---------- 20 metres
(ii)	O.W. II	---------- 40 metres

Static water level below the measuring point

(i)	Obs. well I	---------- 7.68 metres
(ii)	Obs. well II	---------- 7.34 metres

FIG. 38 - a

TIME VS DRAWDOWN CURVE



Analysis of Data

Time-drawdown field data curves of observation wells resemble the typical "time-drawdown-curve" for a confined aquifer, and suggest an unsteady state conditions at the end of pumping. Under the prevailing flow conditions, Theis's and Jacob's method for analysis of drawdown data have been selectively used for the determination of the aquifer parameters (Fig. 37 a, b & 38 a, b).

Evaluation of Results

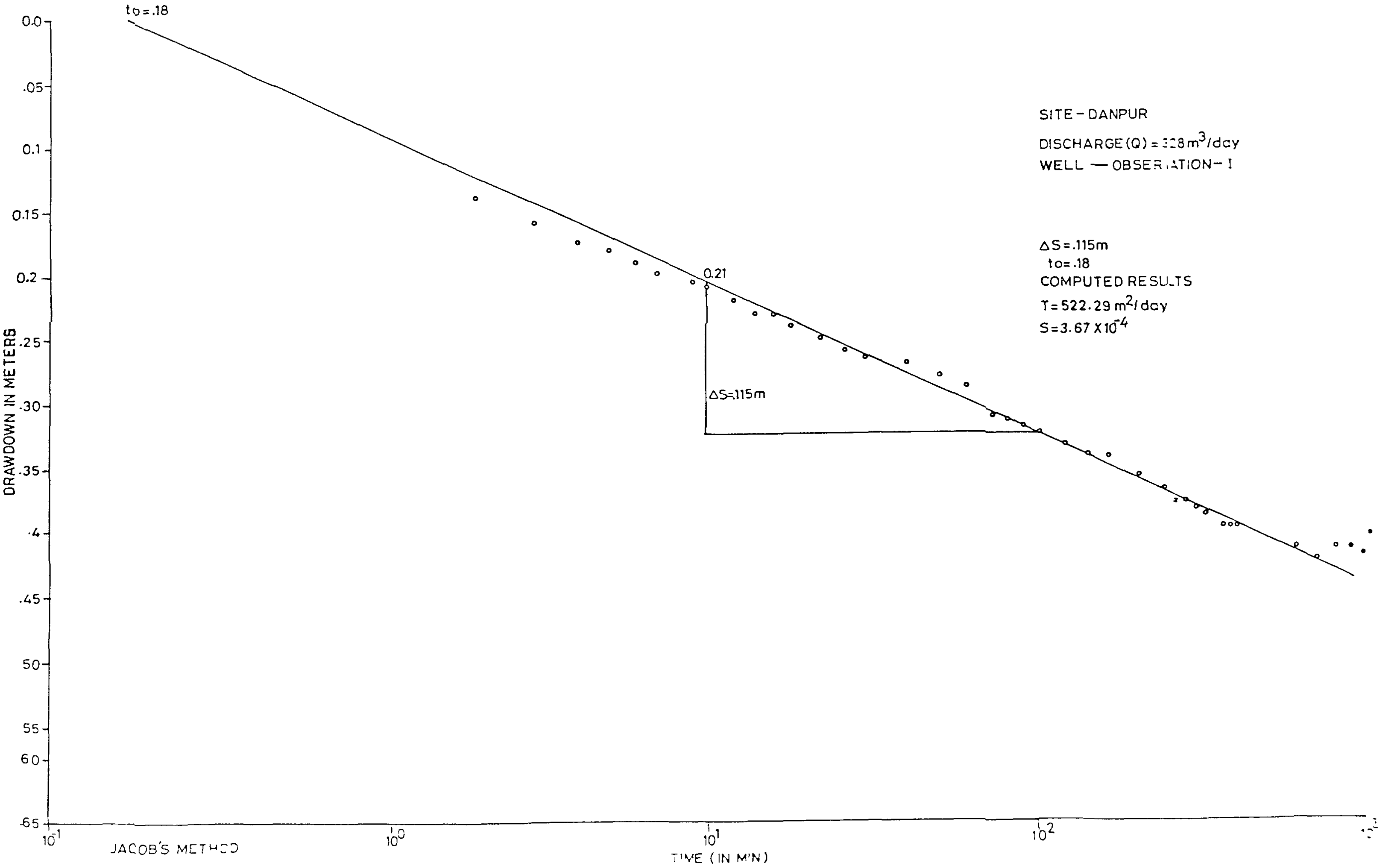
Aquifer parameters evaluated are tabulated as below:

Sl.No.	Method	Plot	Data used	T(m^2/day)	S
1.	Theis	t V_s S	O.W. I	544.05	24.56×10^{-5}
2.	Jacob	t V_s S	O.W. I	522.29	3.67×10^{-4}
3.	Theis	t V_s S	O.W. II	522.29	1.13×10^{-3}
4.	Jacob	t V_s S	O.W. II	523.88	1.36×10^{-3}

Since the field data curves of observation wells match well with Theis type curve, the hydraulic properties of the aquifer determined by Theis method alone have been taken as best approximation of aquifer parameters.

FIG.37-b

TIME VS DRAWDOWN CURVE



The parameters determine by Jacob's method has also yielded matching results.

It may be concluded that tested aquifer has the following hydraulic properties.

(a)	Transmissivity	=	528.12 m^2/day
(b)	Storativity	=	7.75×10^{-4}
(c)	Hydraulic conductivity	=	37.7 m/day

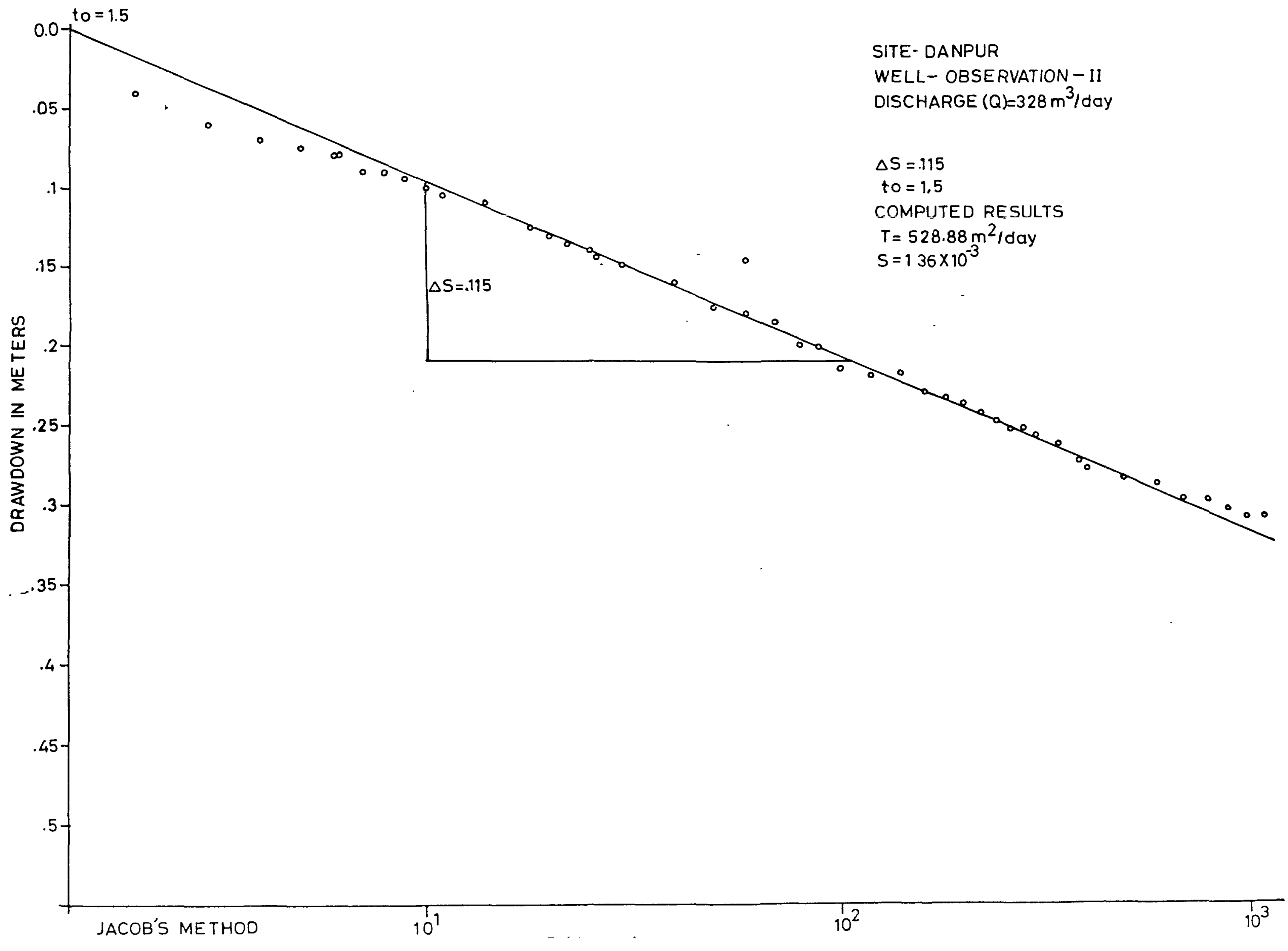
The study shows that aquifers occuring below 50 metre around Atrauli area behave as confined aquifer and those occuring above 50 metres are unconfined in nature.

The pumping tests data analysis of wells at Paharipur, Tikta and Chharra wells show that except for deep aquifers occurring below 90 metres depth below ground level are all interconnected and represent an unconfined state of disposition. The same is assumed true for the entire area lying south and south east of Chharra upto Kasganj.

The study further shows that aquifer in the Ganga-Kali basin are highly potential down to 140 metre bgl and are capable to sustain the future demand of water supply for various uses. However, the declining trend in water level is limited to shallow aquifers, which is resultant of excessive withdrawal with complete disregard to proper well spacing. The depletion of shallow aquifers can be contained through artificial recharge by introducing canal networks.

TIME VS DRAWDOWN CURVE

FIG.38-b



The exploratory drilling carried out by the ONGC shows that the Quaternary alluvium unconformibly rest on Neogene Siwalik sandstone at 360 metre depth at Kasganj. The electrical logging data of the borehole at Kasganj show that the Quaternary sediments down to 360 metre are all fresh water and also the Neogene occurring below 360 down to 410 metres are also fresh. However, the quality of groundwater below 410 metre are of saline nature (Pathak, 1985). In the light of above information it can safely be said that there is an ample scope of large scale groundwater exploration down to 410 metres. It is therefore suggested that all aquifers occurring below 150-410 metres be quantitatively and qualitatively explored thoroughly which should immediately be followed by large scale groundwater development in a systematically planned manner to meet any future demand of water supply in the Ganga-Kali sub-basin.

CHAPTER - V

GROUNDWATER BALANCE

A river basin forms a closed system of surface and groundwater. Therefore, it is essential that various aspects of water in transit through a basin are quantitatively evaluated and definite recommendations in regard to its development are made.

Quantification of groundwater and surface water resources of any basin involves the application of principle of conservation of mass, to account for quantitative changes occuring in various components of hydrologic cycle as applied to the basin. The quantitative changes may be expressed as water balance equation in which the inflow-outflow and change in storage in a period of time are represented by individual components. The groundwater balance may be expressed in the form of an equation as

$$I - O = \pm \Delta S$$

I = Inflow

O = Outflow

ΔS = Change in storage

Groundwater is a replenishable resource. Refined quantitative answers are needed for drawing up plans for its utilization, management and conservation. The heavy demand of groundwater sometimes leads to excessive withdrawals and indiscriminate utilization which is often reflected in serious imbalance of hydrogeological situations at later date. It is therefore, imperative to identify the various recharge and discharge, components of groundwater regime and their effect on its variation with time.

In the state Uttar Pradesh, on one hand, there is a large scale water logging in all the canal command areas whereas in the tubewell irrigated areas water levels show a declining trend due to over-development of the shallow equifers. Moreover, with the advent of high yielding varieties of wheat and paddy which need assured and timely irrigation, has accelerated the pace of groundwater development through large number of shallow farmers' tubewells in rural areas. Under the circumstances, the situation necessitates as far as possible, the precise evaluation of groundwater resources of a basin or part of it.

In the Ganga-Kali sub-basin, the area which lies between Ganga and Nim rivers, is water logged because of the canal networks and consequent seepage, where as the area falling under Nim-Kali interfluves, the groundwater levels show a very well marked declining trends since past few decades. The declining water table can be attributed to the large scale groundwater development through clusters of shallow and deep tubewells.

The study area thus presents extreme situations of water logging on the one hand and the declining trend on the other. However, the scenario necessitates the evaluation of total groundwater recharge and discharge in order to quantify the total water resources of the Ganga-Kali sub-basin in parts of Aligarh and Etah districts of the Central Ganga plain.

Groundwater Recharge:

Evaluation of groundwater recharge parameter forms an important aspect of groundwater resource evaluation. It involves hydrometeriological and hydrological processes taking place on the surface and also involves sub-surface lithological characteristics (Baweja & Karanth, 1980).

Various estimations of groundwater recharge in the country have been made (Rao, 1965; Raghava Rao _et al._, 1964; Irrigation Commission 1972 and Pathak, 1982), while the earlier estimations were based on adhoc norms not supported by the field tests. A large amount of data generated in recent years as a result of the extensive multi-disciplinary project studies undertaken by both the Central Groundwater Board as well as by State Groundwater Department have made realistic appraisals rather easier. The major source of groundwater recharge in the area are as under:

(1) Recharge through rainfall

(2) Recharge through canal seepage

(3) Recharge through irrigation return flow

There are various methods to estimate groundwater recharge, two of them are as under.

(1) Water-table fluctuation method

(2) Rainfall-recharge method Ad-hoc norms

In view of the prevailing irrigation pattern in the area the quantum of seepage to the aquifers will be very significant. Hence, the estimation by seasonal fluctuation and specific yield have been adopted for the evaluation of groundwater recharge in the present study.

Monsoon (Recharge)

Geographical Area	=	1340 sq km
Water table fluctuation	=	1.3 m
Specific yield	=	9%
I.M.D. normal yearly rainfall(mm)	=	697.2 mm
I.M.D. normal monsoon rainfall	=	624.35
I.M.D. normal non-monsoon rainfall	=	43.8
Average rainfall of the observation year (mm)	=	788.15

Monsoon recharge have been calculated by the formula given by groundwater estimation committee.

Monsoon Recharge = (Geog. Area x Sp. yield x W.T. fluctuation) + gross kharif draft - (monsoon canal seepage + monsoon seepage from surface water irrigation + monsoon recharge from groundwater irrigation) x

$$\frac{\text{Normal monsoon rainfall}}{\text{Average monsoon rainfall}}$$ + monsoon recharge from surface irrigation + monsoon recharge from canal seepage.

$$= (1340 \times 0.09 \times 1.3)+56.27-(46.57+97.52+14.06) \times \frac{697.2}{788.5} +$$

$$97.52+46.57+213.05-(158.15)\ 0.88 + 97.5+46.57$$

$$= 213.05 - 139.83 + 97.5 + 46.57$$

$$= \underline{217.29 \text{ M.C.M.}}$$

Monsoon recharge for the entire basin has been estimated to be 217.29 M.C.M.

B. Non-Monsoon Recharge:

Non-monsoon recharge estimated for the basin is given below.

Geographical area	=	1340 square kilometer
Non-monsoon rainfall	=	46.7 mm
Infiltration factor	=	25%
Non-Monsoon Recharge	=	$\frac{1340 \times 0.25 \times 46.7}{10^3}$
	=	15.64 M.C.M.
Total non-monsoon Recharge	=	15.64 + 102.69 + 49.06
	=	169.39 M.C.M.

Recharge through return seepage from applied irrigation:

To evaluate the irrigation return flow to the groundwater, the irrigated area and volume of water applied for irrigation are taken into consideration for working out the total volume of water applied, of which 30% is assumed to return to groundwater body. Crop-wise return seepage in the area has been calculated in the basin which is given as below.

Recharge through irrigation return flow

Crop Type	Area Irrigated	Average wetted depth ((M)	Irrigation Water applied	Seepage factor %	Seepage M.C.M.
Mansoon					
1. Kharif	609.5	0.4	243.8	40%	97.52
Non-Monsoon					
2. Rabi	823.8	0.4	329.5	30%	98.85
3. Zaid	85.49	0.15	12.82	30%	3.84

The total quantum of the irrigation return flow is computed to be 200.1 M.C.M.

Quantum of Recharge due to Canal Seepage

The seepage losses from the canal have been estimated by using the formula given by Satish Chandra (1983). He opined that the following formula was applicable to the alluvial region of Uttar Pradesh.

$$W = 0.005\ C\ (B + D)^{0.67} \qquad \text{.......... (1)}$$

where,

W = recharge from canal in $m^3/s/km$ length of unlined canal.

B = bed width, in m.

D = water depth in m.

C = a constant being 1.0 for intermittently running and 0.75 for constant running canal.

Using the above formula, the quantum of seepage from canal net work in the area has been calculated here as below.

Recharge from Canal Seepage

(a) Seepage from the Lower Ganga Canal

Total length of canal traversing through the study area = 37 km

B = 73.17 m

D = 3.5 m

C = 0.75

$$W = 0.005\ C\ (B + D)^{0.67}$$

$$= 0.005 \times 0.75\ (73.17 + 3.5)^{0.67}$$

$$= 0.0686\ m^3/s/km$$

Total seepage in the basin through the total length of the Lower Ganga canal.

$$= 0.0686 \times 37$$

$$= 2.54 \ m^3/s$$

Total Non-Monsoon Recharge by the Lower Ganga canal

$$= 2.54 \times 60 \times 60 \times 24 \times 182$$

$$= 39.94 \text{ M.C.M.}$$

Similarly monsoon recharge by lower Ganga canal = 39.94 M.C.M.

Seepage from intermittently running Upper Ganga Canal

Total length of canal traversing through the study area = 34 km

$C = 1$

$B = 5.64$

$D = 0.94$

$$W = 0.005 \ C \ (B + D)^{0.67}$$

$$= 0.005 \times 1 \ (5.64 + 0.94)^{0.67}$$

$$= 0.005 \ (3.53)$$

$$= 0.017 \ m^3/s/km$$

Total seepage in the basin through the total length of the canal

$$= 34 \times 0.017$$

$$= 0.601 \ m^3/s$$

Monsoon Seepage

Total running days during monsoon = 107

$$= 0.601 \times 60 \times 60 \times 24 \times 107$$

$$= 5.56 \text{ M.C.M.}$$

Non-Monsoon Recharge through the Upper Ganga Canal

Total running days during non-monsoon = 144

= 0.601 x 60 x 60 x 24 x 144

= 7.47 M.C.M.

(c) **Seepage from Hardoi Distributary**

Total length of canal = 11.7 km

B = 3.04 m

D = 0.625

C = 1

W = $0.005\ C\ (3.04 + 0.625)^{0.67}$

= 0.005 x 1 (2.38)

= 0.0119 $m^3/s/km$.

Total Seepage through the entire length of Hardoi Distributary

= 0.0119 x 11.77

= 0.140 $m^3/s/km$

Monsoon Seepage through the Hardoi Distributary

Total running days during monsoon = 32

= 0.140 x 60 x 60 x 24 x 32

= 3870.72

= 0.38 M.C.M.

Total Non-Monsoon Seepage

Total running days during non-monsoon = 35

$$= 0.140 \times 60 \times 60 \times 24 \times 35$$

$$= 0.42 \text{ M.C.M.}$$

(d) **Seepage from Dadon Distributary**

Total length of canal = 10.5 km

$$B = 2.13 \text{ metre}$$

$$D = 0.556 \text{ metre}$$

$$W = 0.005\ (2.13 + 0.556)^{0.67}$$

$$= 0.005\ (1.93)$$

$$= 0.0096\ m^3/s/km$$

Total seepage in the area through the total length of distributary

$$= 0.0096 \times 10.5$$

$$= 0.101\ m^3/s$$

Total seepage through Dadon distributary during monsoon

Total running days during monsoon = 28

$$= 0.101 \times 60 \times 60 \times 24 \times 28$$

$$= 0.24 \text{ M.C.M.}$$

Total seepage during non-monsoon period

Total running days during non-monsoon = 48

$$= 0.101 \times 60 \times 60 \times 24 \times 48$$

$$= 0.41 \text{ M.C.M.}$$

(o) Mahowa Distributary

Canal length = 12.4 km

$$B = 1.37 \text{ m}$$

$$D = 0.57 \text{ m}$$

$$W = 0.005\ C\ (B + D)^{0.67}$$

$$= 0.005 \times 1\ (1.37 + 0.57)^{0.67}$$

$$= 0.005 \times 1.55$$

$$= 0.007 \text{ m}^3/\text{s/km}$$

Total seepage in the basin through the total length of the distributary.

$$= 0.007 \times 12.4$$

$$= 0.096 \text{ m}^3/\text{s}$$

Monsoon Seepage from Mahewa Distributary

Total running days during monsoon = 28

$$= 0.096 \times 60 \times 60 \times 24 \times 28$$

$$= 0.23 \text{ M.C.M.}$$

Non-Monsoon Seepage

Total running days during Non-Monsoon = 51

$$= 0.096 \times 60 \times 60 \times 24 \times 51$$

$$= 0.42 \text{ M.C.M.}$$

(f) **Bazidpur Distributary**

Total length of canal = 13.14 km

$$B = 1.21 \text{ m}$$

$$D = 0.48 \text{ m}$$

$$W = 0.005 \times C\ (B + D)^{0.67}$$

$$= 0.005 \times 1\ (1.21 + 0.48)^{0.67}$$

$$= 0.005 \times 1.42$$

$$= 0.0071 \text{ m}^3/\text{s/km}$$

Total seepage in the area = 13.14 x 0.0071

= 0.093 M.C.M.

Monsoon Seepage

Total running days during monsoon = 28

$$= 0.093 \times 60 \times 60 \times 24 \times 28$$

$$= 0.22 \text{ M.C.M.}$$

Non-Monsoon Seepage

Total running days during non-monsoon = 51

$$= 0.093 \times 60 \times 60 \times 24 \times 51$$

$$= 0.40 \text{ M.C.M.}$$

Total Non-Monsoon Seepage through the canals and distributaries.

$$= a + b + c + d + e + f$$

$$= 39.94 + 7.47 + 0.42 + 0.41 + 0.42 + 0.40$$

$$= 49.06 \text{ M.C.M.}$$

Total Monsoon Seepage through canals = 39.94 + 5.56 + 0.38 + 0.24 + 0.23 + 0.22

= 46.57 M.C.M.

Cross Groundwater Recharge in the Basin

The gross groundwater Recharge = Monsoon Recharge + Non-monsoon Recharge

= 217.29 + 169.39

= 384.68 M.C.M.

The gross groundwater recharge in the entire area under investigation is estimated as 384.68 M.C.M.

Recoverable Recharge

85% of the gross recharge as obtained above is taken to be recoverable recharge for irrigation.

Total groundwater resource for irrigation

= Gross Recharge x 0.85

= 384.68 x 0.85

= 326.97 M.C.M.

GROUNDWATER DRAFT :

The discharge of groundwater in the area mainly takes place through state tubewells, shallow farmer's tubewells, pumping sets and persian wheels. Besides a large quantity of the ground water joins the bounding rivers i.e. the Ganga and Kali, however, the discharge or base flow into the rivers etc. is not taken into the consideration due to paucity of data. In present study, only the gross annual draft from the existing groundwater structures is taken into account for calculating the groundwater discharge. In the study area, there are 343 deep tubewells, 6142 shallow farmers' tubewells, 4096 pumping sets and 1212 persian wheels.

The unit drafts for these groundwater structures have been estimated by the State Groundwater Department, Uttar Pradesh, for this area (Hasan et al. 1982) have been utilized in the evaluation of the groundwater draft.

Groundwater draft in the basin

(a)	Total number of State tubewells	=	343
	Unit draft of each tubewell	=	0.17 M.C.M.
	Total draft by the State tubewells	=	343 x 0.17
		=	58.31 M.C.M.
(b)	Draft by shallow farmers' tubewells		
	Total number of shallow tubewells	=	6142
	Unit draft for each shallow tubewell	=	0.0188 M.C.M.
	Total draft	=	6142 x 0.0188
		=	115.77 M.C.M.

(c) Draft by pumping

Number of pumping sets	=	4096
Unit draft for each pumping set	=	0.0109 M.C.M.
Total draft	=	4096 x 0.0109
	=	44.95 M.C.M.

Draft by Persian Wheels

Total number of persian wheels	=	1212
Unit draft for each persian wheels	=	0.005 M.C.M.
Total draft	=	1212 x 0.005
	=	6.06 M.C.M.

Total draft in the basin:

= 58.31 + 115.77 + 44.95 + 6.06

= 225.09 M.C.M.

Monsoon draft = 56.27 M.C.M.

(25% of the total draft is taken as monsoon draft)

Net Annual draft = 157.56 M.C.M.

Water Balance

$I - O = \pm \Delta S$

$I = 326.97$ M.C.M.

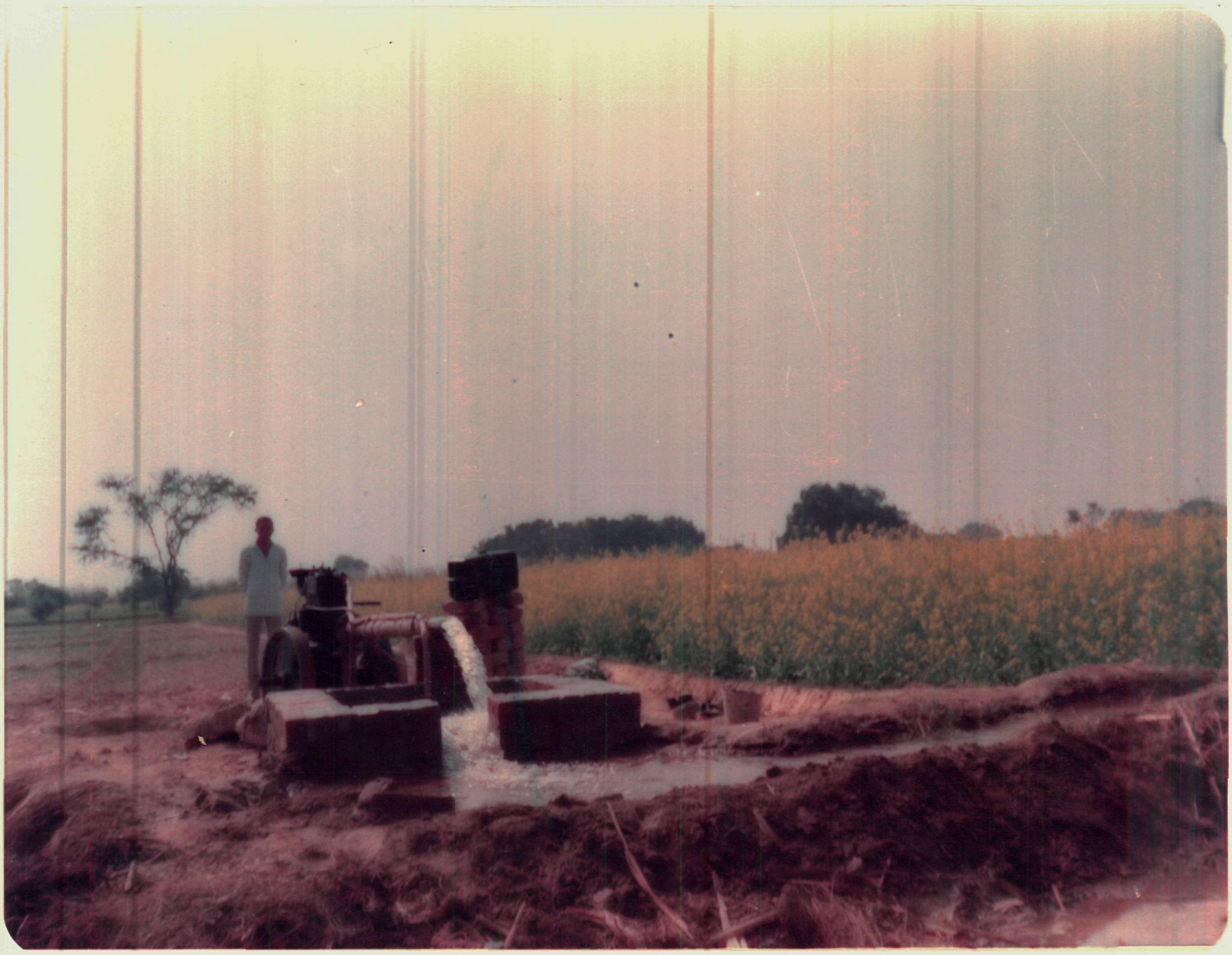
$O = 157.56$ M.C.M.

$326.97 - 157.56 = \pm \Delta S$

169.41 M.C.M. $= \pm \Delta S$

Plate 7 - Shallow farmer tubewell.

PLATE 7



The above evaluation of groundwater resource in the area shows that 169.41 M.C.M. utilizable resource lies in balance, hence there is an ample scope for further development of groundwater.

Groundwater Potential and Stage of Development

Gross groundwater Recharge M.C.M.	Net groundwater recharge (85% of gross)	Gross groundwater draft M.C.M.	Net Ground water draft	Balance G.water available	Stage ground water development
384.68	326.97	225.09	157.56	169.41	48.18%

STAGE OF GROUNDWATER DEVELOPMENT

The stage of groundwater development in the investigated area as per the 'ARDC' 1979 (Agricultural Refinance and Development Corporation) norms is evaluated as follows.

$$\text{Stage of groundwater development} = \frac{\text{Net yearly draft}}{\text{Net recoverable recharge}} \times 100$$

$$\text{Stage of groundwater development in the Ganga-Kali sub-basin} = \frac{157.56 \times 100}{326.97}$$

Area where the stage of groundwater development is less than 65% falls under the 'White' where the stage of groundwater development ranges between 65 to 85% under 'grey' and an area where the stage of groundwater development is more than 85% falls under the 'dark' categories.

Accordingly, the stage of groundwater development in the area works out to be 48.18% which naturally puts it under the 'white' category with the sole exception of Atrauli Block covering an area of 279 square kilometer around Atrauli town where the stage of groundwater development has exceeded 65% and hence falls under the 'grey' category.

In view of 48.18% of groundwater development, there is large groundwater surplus available for further development in the basin which can be utilized through the construction of atleast 588 deep tubewells with pumping rate of 150 m^3/hour at a drawdown varying between 4 to 6.5 metres with a well spacing of 237 metres. Besides it about 3670 shallow tubewells having discharge of 30-50 m^3/hour at a economic drawdown and well spacing of 150 metre may also be constructed, in a phased manner over a period of 5 years. The above evaluation of 1694 M.C.M. of utilizable resource potential pertains to the water table aquifers only. The confined aquifers occuring below 90 metre down to 150 metre depth have enormous groundwater resource potential as evinced by their aquifer characteristics ($T = 528.12\ m^2/day$ $S = 7.75 \times 10^{-4}$) which are being abstracted and may further be tapped through large numbers of tubewells spread over the entire area.

At present the groundwater development is confined down to depth of 150 metres only. The thickness of alluvium is only 360 metres which over lies 260 metre thick Neogene Siwalik sandstone which further down, inturn unconformably overlies the upper Vindhyans at 620 metres below the land surface. However, the aquifer down to depth of 410 metres are fresh which includes 360 metres of Quaternary alluvium and 150 metre Siwalik sandstone. Aquifers, occurring in depth range of 410-620 metres are reported to be saline in nature (Pathak, 1985). However, future development of groundwater in the basin should be taken up in a big way through a systematically planned exploratory drillings programme to evaluate precisely the total groundwater resource potential of the Ganga-Kali sub-basin down to the depth of 410 metres or more.

Besides the above suggestion a constant monitoring of water level in the basin must be carried out simultaneously in order to keep watch on any adverse effect which may entail as consequent to heavy withdrawal of groundwater. There should be an increasing emphasis on basin wise analysis of groundwater system. In the years to come hydrogeologist working in the Ganga-Kali sub-basin should adopt a system analysis approach to visualise the effects throughout whole hydrologic systems of various groundwater exploration development and management projects.

Finally, according to Walton "There is increasing awareness that wherever the nation hopes to make full use of its resources to meet its progressively increasing requirements for water, it must develop and maintain a continuing inventory that will show the quantities of water passing through each phase of hydrologic cycle (Precipitation, Infiltration, runoff evapotranspiration, and groundwater) and permit a periodic accounting of the water storage in the soil, in surface reservoir and in groundwater reservoirs. With this quantitative information, and application of sound hydrologic principles, full development of water resources can be achieved".

CHAPTER - VI

HYDROCHEMISTRY

Quality of groundwater is far more important like its quantity. The water being universal solvent, its purity can not remain intact. The concentration of elements in natural water is governed by several factors like nature of strata through which it is circulating, soil characteristics, contamination due to activities of man etc. Briefly, the chemical quality of groundwater is an index of its complex flow history.

In order to study water quality in the study areas, samples from surface and sub-surface water bodies were collected. In all, 77 water samples were collected during June 1988 from different groundwater structures spread over the entire area. Besides it, 10 water samples were randomly collected during June 1989 to check the change in water quality, if any. Out of 77 samples, 45 were analysed for major element and 47 samples were analysed for trace element studies.

Similarly water samples collected from the Ganga, and Kali rivers and the lower Ganga canal were also analysed for major and trace element studies.

METHODOLOGY AND MATERIALS USED

Sampling Techniques:

The sample for major ion chemistry were collected in well cleaned 1 litre capacity double stoppered polythene bottles during

June, 1988, 1989. Prior to sampling the bottles were carefully cleaned with concentrated HCl then rinsed with tap water and finally with distilled water. The bottles were then dried at 103°C for one hour, cooled to room temperature, capped and labelled. Finally, the water sample bottles were rinsed with the water to be sampled. The samples were taken from different groundwater structures like open wells, shallow and deep tubewells in duplicate as per the normal procedures (Handa, 1989). One group of water samples was kept for physico-chemical examination, while the other was immediately acidified with 10 ml 6N HNO_3 for the trace elements determination. Sample after collection were capped and sealed with wax immediately in field itself.

Analytical Procedure:

The physico-chemical characteristics of water samples were determined according to the standard methods (APHA, 1975; Jackson, 1958; Trivedi and Goel, 1984) in the geochemical laboratory of the Geology Department, A.M.U., Aligarh. Samples for heavy metal analysis were filtered through filter paper Whatman No. 42 and 500 ml of the filtered samples were acidified again with 5 ml of $NHNO_3$ before concentrating to 50 ml (Parker, 1972). The concentrated samples for heavy metal like Zn, Cu, Fe, Mn, Sr, Li concentration were analysed using G.B.C. 902 Double Beam Atomic Absorption Spectrophotometer in the same labaoratory. A blank sample was made for each spectrophotometric analysis in order to account for any instrumental error.

Trace element like Pb, Cd, Cr were analysed by Inductive Coupled Plasma Spectrophotometer at USIC, Roorkee. The analytical techniques adopted for the estimation of various constituents have been given in the table as below:

Table 10: Analytical techniques for chemical analysis.

S.No.	Constituents	Techniques employed
1.	pH	pH conductometer (consort-Belgium)
2.	EC	"
3.	CO_3^{--}	Titration
4.	HCO_3^-	"
5.	Cl^-	"
6.	SO_4^{--}	Turbidimetric
7.	Total Hardness	Titration
8.	T.D.S.	Volumetric
9.	Na^+	Atomic Absorption
10.	K^+	Spectro photometer
11.	Ca^{++}	"
12.	Mg^{++}	"

RESULTS

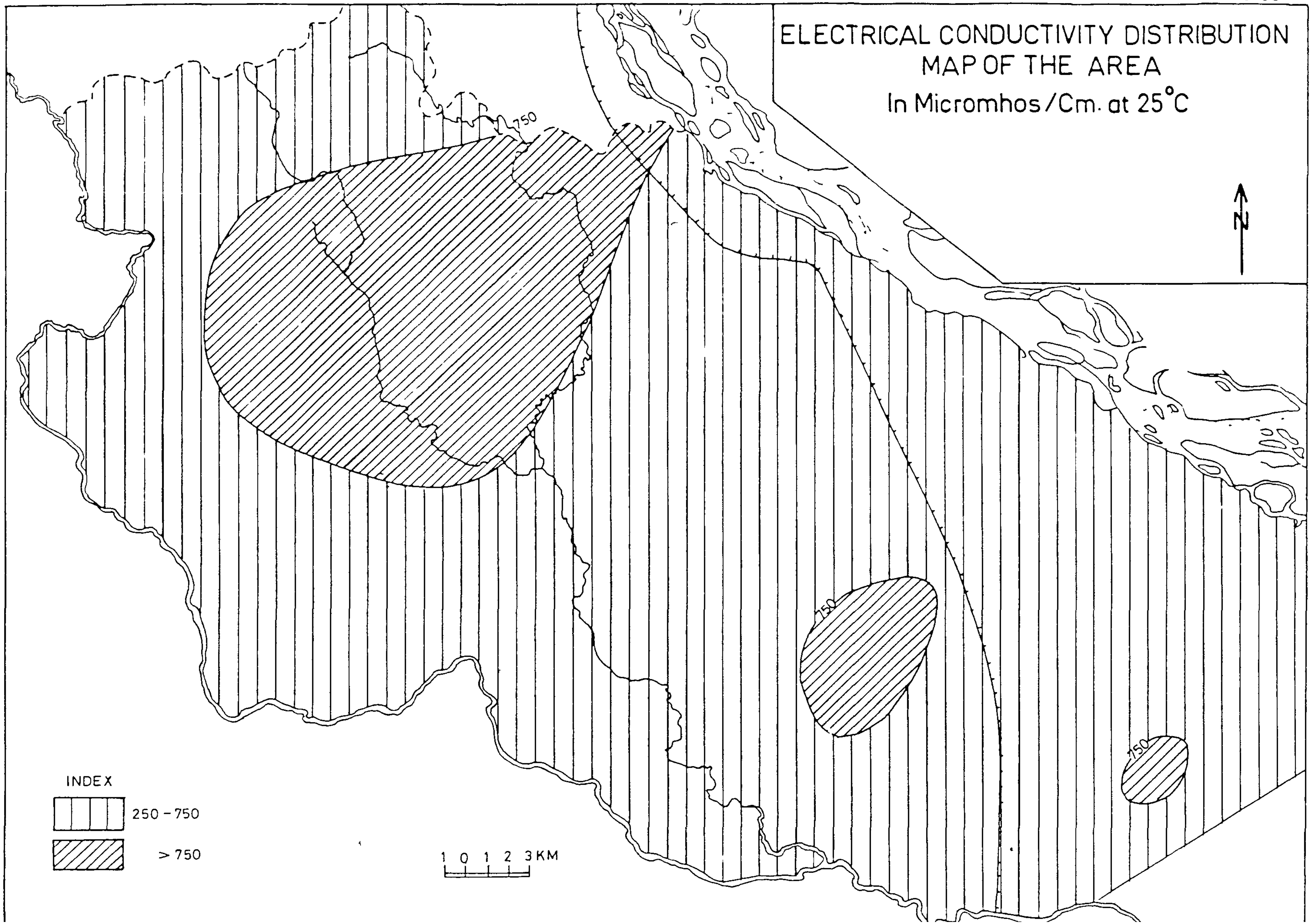
Analytical results of water sample collected from observation wells and deep tubewells and rivers and canals are given in Appendices. (VIII, IX, X & XI)

Hydrogen Ion Concentration:

The pH refers to the activity of hydrogen ion concentration in the water, expressed as the negative logarithm(base 10) of the H^+ activity in moles per litre. At a pH of 7, the H^+ activity is 10^{-7} mol/l and the solution is considered neutral while the pH is less than 7 behaves as an acid. Further, at pH above 7, the solution reacts like base. The European standards for the drinking water of W.H.O. do not give any range of values for the pH. However, in the International Edition of W.H.O., it is said that pH is likely to give rise off taste and to promote corrosion. The highest desirable level quoted is 7 to 8.5 while the maximum permissible level is given as 6.5 to 9.2. In the report of the committee on water quality criteria of U.S. Department of Interior the permissible range is given as 6.5 to 8.5. The above range of value was quoted as desirable criteria.

In general, the groundwater in the area is moderately alkaline in reaction. pH generally was found to vary from 7.5 to 8.8 during the year 1988, while in June 1989 it ranged between 7.5 to 8. The pH values of the groundwater samples of the study

FIG 39


ELECTRICAL CONDUCTIVITY DISTRIBUTION
MAP OF THE AREA
In Micromhos/Cm. at 25°C
N
750
750
750
INDEX
250 - 750
> 750
1 0 1 2 3 KM

area indicate that though the groundwater is alkaline in reaction but it falls well within the limit.

ELECTRICAL CONDUCTIVITY (umhos/cm)

Electrical conductivity is a measure of the mineralisation and is indicative of the salinity of groundwater. It is a useful determination in order to see if the quality of water has suffered an exceptional rapid change.

The electrical conductivity with 400 umhos/cm at 25°C is considered suitable for human consumption. In the study area, electrical conductivity values of water samples were found to range between 261 to 1500 umhos/cm during June 1988. In 1989 it ranged between 345 to 1057 umhos/cm. The (Figure-39) shows the electrical conductivity distribution in the study area. A perusal of figure indicates that in the major parts of the area electrical conductivity ranges between 250 to 750 umhos/cm, except at Atrauli area where the E.C. is observed more than 750 umhos/cm. Higher values of electrical conductivity were also recovered at Ghinauna, Ikhauna and Sankra village i.e. 700, 850 and 1500 umhos respectively.

MAJOR ELEMENTS

Carbonates:

The concentration of carbonates was found to range between 0 to 36 ppm during June 1988 and between 6 to 21 ppm in 1989.

In general, the concentration of carbonate in the study area was found less than 10 ppm.

Bicarbonates :

The bicarbonate content in the groundwater is dependent upon the partial pressure of carbondioxide in the soil and consequently bicarbonate shows wide fluctuations. Bicarbonate associated with carbonates affect the alkalinity of the groundwater. The bicarbonate concentration in the study area was found to range between 177 to 592 ppm during 1988 and 268 to 412 ppm during 1989. The groundwater containing 600 ppm of bicarbonate is considered fairly safe and good for irrigation and domestic purposes. A perusal of (appendix - VIII & X) shows that concentration of bicarbonate lies well within the permissible limits.

Chloride :

The concentration of chloride in the groundwater of the study area varies between 17.75 to 186 .7 ppm during June 1988 and between 43 to 142 ppm during June 1989.

As per the standards of I.C.M.R. plainly, puts the desirable limits of chloride in drinking water to be 250 ppm and excessive limits as 1000 ppm it is considered suitable for drinking as well as for irrigation purposes. The (W.H.O., 1984) European standards suggests that above 200 mg/litre there may be trouble in corrosion of hot water system and they suggest that in no circumstances should the level exceed 600 mg/litre. The infants and young children may suffer if they consume water high in chloride as their delicate kidney tissues may be damaged by the higher osmotic pressure brought about by the presence of high concentration of salts.

Appendix shows that concentration of chloride is with in the permissible limits.

Sulphate :

High concentration of sulphates in association with sodium or magnesium have an aperient action and therefore note has to be taken on concentrations of the other substances when one is considering the permissible concentration of sulphate.

Excess of sulphate might give rise to gastrointestinal irritation when combined with magnesium or sodium. At higher concentration sulphate can have laxative effect (W.H.O., 1984). Water containing magnesium sulphate at levels 1000 mg/l acts as purgative in adults while lower concentration may affect new users and children. Sulphate generally have less affect on taste than chlorides and carbonates. Taste threshholds vary according to the associated cations and are in range of 200-500 mg/l.

The sulphate concentration in the water samples of study area was found to range between 43 to 271 ppm during 1988 and 75 to 200 ppm during 1989. The above concentration of sulphate is fairly safe for drinking purpose.

Sodium :

Sodium concentrations in drinking water depend on factors such as hydrogeological conditions, the season of the year and industrial activities. As per the recommendations of W.H.O., 1978, the intake of sodium should be reduced in order to protect human health as it contributes to the large incidence of high blood pressure and possibly cardiac failures too. Moreover, the sudden cot death of infants is attributed to the high sodium content of the artificial feeds (prepared with water & containing high sodium content) and dried cow milk.

The guideline value of sodium is given as 200 mg/litre which is based on taste consideration (W.H.O., 1984). The concentration of sodium in the groundwater of the study areas was found to range between 13.15 to 150 ppm during June 1988 and between 30 to 139.2 ppm during June 1989. The highest concentration of sodium (150 ppm) was recorded in the groundwater sample collected from Rukhela observation well. The higher concentration may possibly be due to lithological control. The lithological sequence at Rukhela is as follows:

Lithology	Depth range
0 - 3	Clay
3 - 6	Clay Kankar
6 - 18	Sand

The pre and post-monsoon water level recorded are 9.1 and 8.6 metre respectively, yet there is large scale soil salinization due to three metres thick hard pan which occur three metres below the land surface and immediately below it lies 12 metre thick aquifer. During the monsoon season the salts percolates into the aquifer lying below 6 metre depth raising thereby the high level of sodium.

Potassium

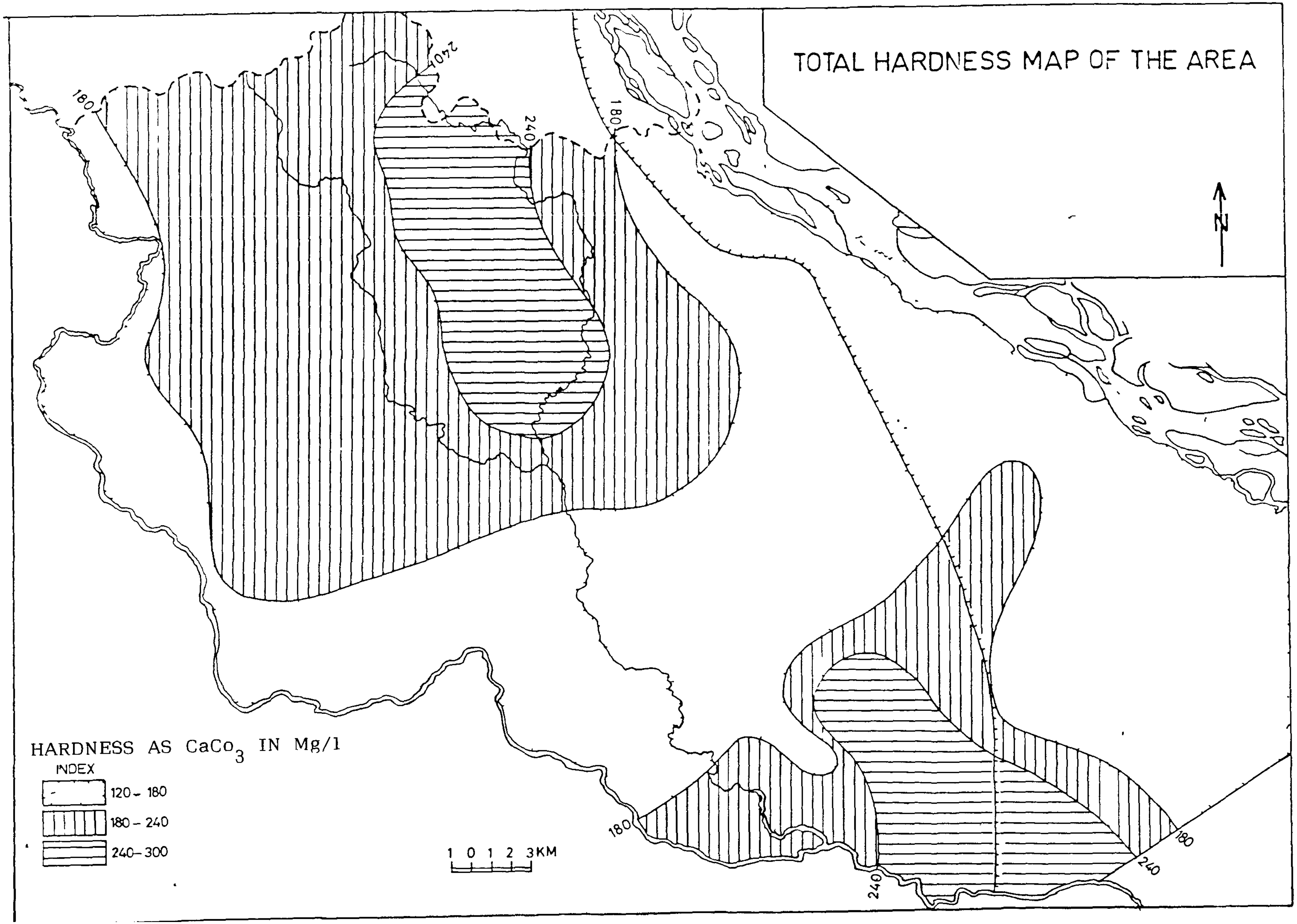
The analytical results show that the concentration of Potassium varies from 8 to 85 ppm during June 1988 and 17.7 to 135 ppm during June 1989. The concentration of K is generally low in groundwater of the area. No desirable or excessive limit for K concentration is fixed but 1000 to 2000 ppm is considered as the excessive limit for K in the drinking water.

Calcium

It is the most common constituent present in the ground water of the area. The dissolved CO_2 species generally control the Ca^{++} ion concentration in the groundwater (Pathak, 1980). The calcium forms an essential element and human body normally requires 0.7 to 2 gram intake per day.

The concentration of Ca in the groundwater of the area ranged between 29.2 to 74 ppm during June 1988 and 29.3 to 60 ppm during June 1989. The highest desirable level of calcium in drinking water

FIG 40


TOTAL HARDNESS MAP OF THE AREA
N
180
240
180
240
180
240
180
240
180
240
HARDNESS AS $CaCo_3$ IN Mg/1
INDEX
120 - 180
180 - 240
240 - 300
1 0 1 2 3KM

is 75 ppm and maximum permissible level is 200 ppm (W.H.O., 1984; I.C.M.R., 1975). The values recorded for calcium are well with in the limit.

Hardness

There is evidence that death rates from cardiovascular diseases are inversely correlated with the hardness of water, but there is insufficient proof that either the calcium or the magnesium is directly involved. Public acceptibility of the degree of hardness of water may vary considerably from one community to another, depending upon local conditions and in some instances a water hardness in excess of 500 mg/l is tolerated.

The taste threshhold for the calcium ion is in the range of 100-300 mg/l depending upon the associated anion. Depending the interaction of other factors, such as pH and alkalinity, water with a hardness above approximately 200 mg/l may cause scale deposition in the distribution system. The guide line value for hardness at 500 mg/l (as $CaCO_3$) is based on taste and house hold use consideration (W.H.O., 1984).

In water samples of the study area total hardness as $CaCO_3$ ranges between 140 to 360 ppm. Figure 40 shows the total hardness distribution in the area. The table given below shows the percentage of samples falling in different classes on hardness.

S.No.	Class	Range of hardness as $CaCO_3$ (ppm)	Percentage
1.	Soft	0 - 60	nil
2.	Moderately based	61 - 120	nil
3.	Hard	121 - 180	42.85
4.	Very hard	> 180	57.14

A perusal of the above table shows that the groundwater in the area is hard to very hard in nature.

Magnesium

The Indian council of Medical Research (1975) has given 50 ppm as an acceptable and 100 ppm as the permissible limits for the magnesium in drinking water. The magnesium content of groundwater samples ranges between 14 to 72 ppm during 1988 and 18 to 41 ppm during 1989. Data show that most of the water samples contain relatively small amount of magnesium than Ca. Further, all values are well within the limit of I.C.M.R. (1975).

Total Dissolved Solids

The total dissolved solids consist mainly of inorganic substances. The principal constituent of which are Calcium, Magnesium, Sodium, Bicarbonates, Cloride and Sulphates. An important aspect of TDS with respect to drinking water quality is the effect on the taste.

The palatibility of water with a TDS level less than 600 mg/litre is generally considered to be good whereas at TDS levels greater than 1200 mg/litre drinking water becomes increasingly unpalatable (W.H.O., 1984); Davis et al. (1966) has given a classification of water based on T.D.S. which is as follows:

Types of water	Concentration of Total Dissolved Solids in ppm
Fresh water	0 - 1000
Brakish water	1000 - 100000
Salty water	100000 - 1000000
Brine	> 1000000

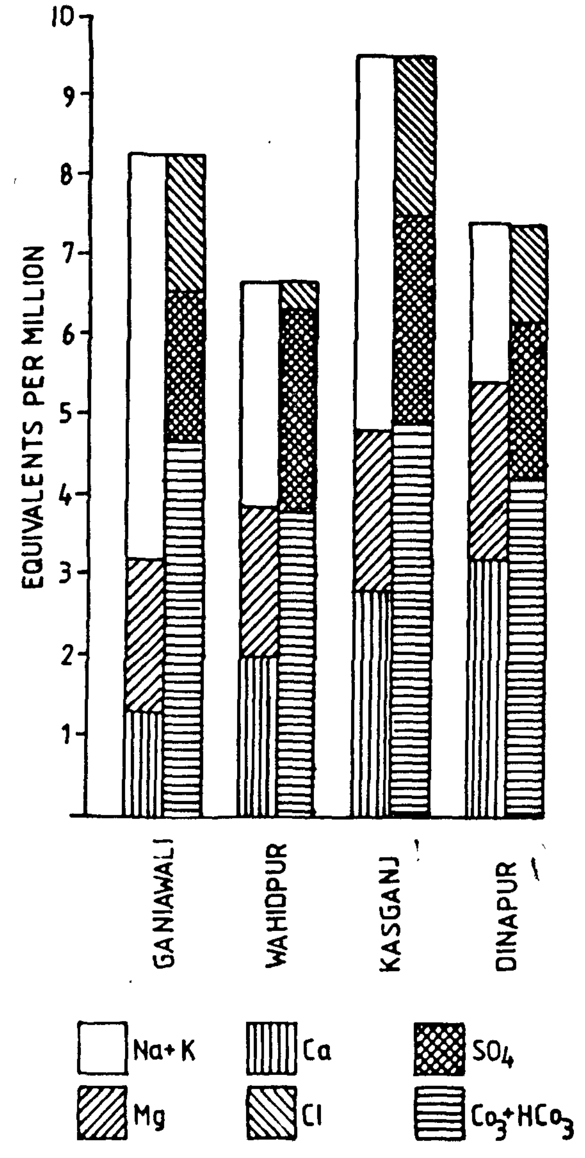
In the groundwater of the area, T.D.S. ranges between 200 to 575 ppm during June 1988 and 225 to 688 ppm in 1989, which puts the groundwater of the area into the fresh category.

GRAPHICAL REPRESENTATION OF CHEMICAL ANALYSIS DATA

Results of analysis of chemical quality of groundwater may be difficult to interpret. To overcome this, graphic representations are useful for display purpose for comparing analyses and emphasizing similarities and differences. A variety of techniques have been

FIG. 41

VERTICAL BAR GRAPH REPRESENTING ANALYSIS OF GROUNDWATER QUALITY AT FOUR DIFFERENT PLACE



developed for showing major chemical constituents. Following methods are used to show the results of chemical analysis in present study.

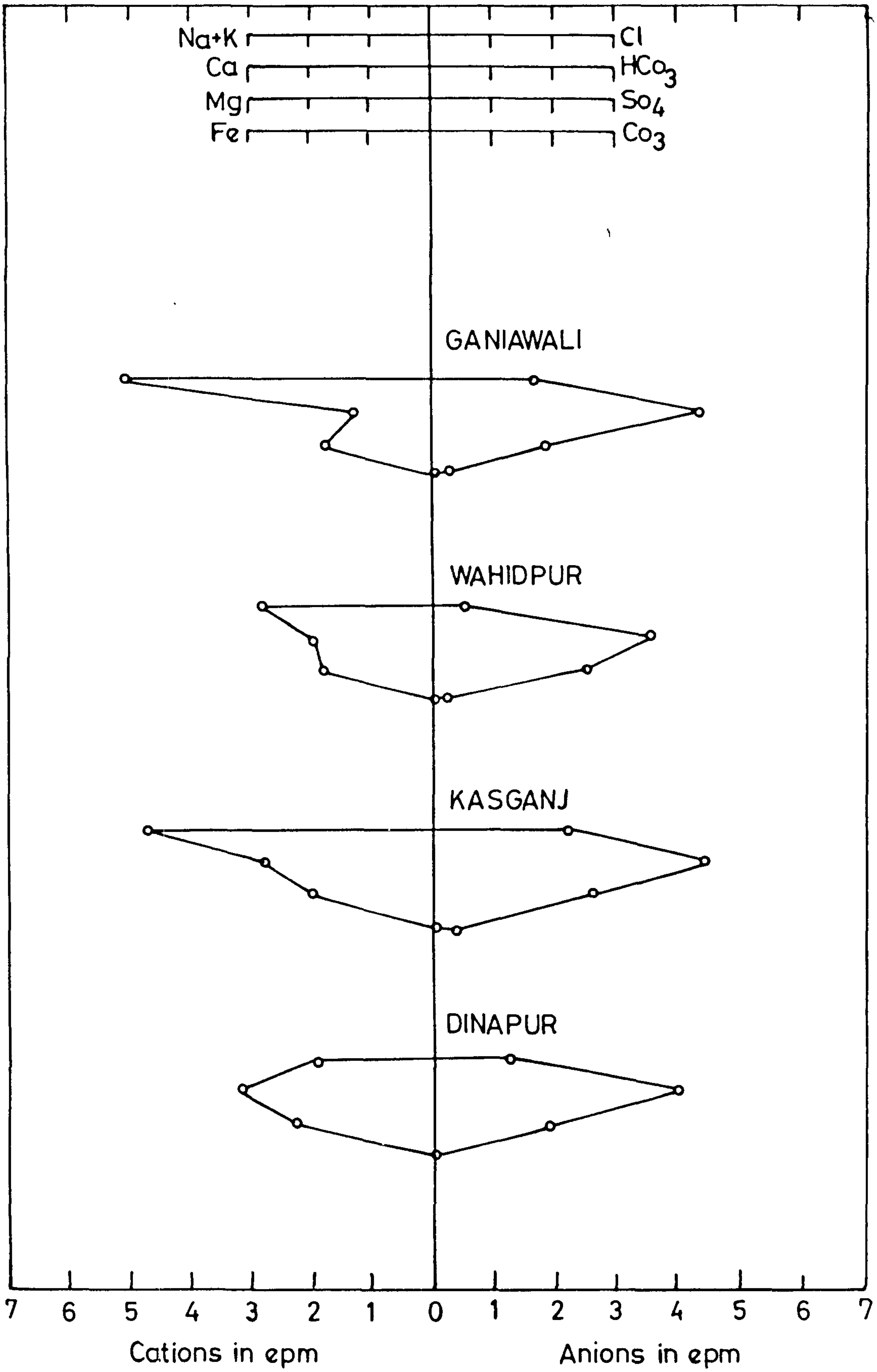
Bar-diagram

In this diagram each analysis appears as a vertical bar having a height proportional to the total concentration of anions or cations expressed in milli equivalent per litre. The left half of a bar represents cations and right half anions. These segments are divided horizontally to show concentrations of major ions group of closely related ions and identified by distinctive shading patterns. The chemical analysis data of four water samples were selected from four different places and bar diagram was prepared (Fig. 41). The figure reveals that at Ganiawali among the cations concentration of Na+K is high which is followed by the Mg. The concentration of Ca is slightly low. Among the anions the concentration of $HCO_3^- + CO_3^{--}$ is high and SO_4^{--} and Cl^- are almost in equal proportions. The highest concentration of anions and cations are found at Kasganj water sample. At Dinapur which falls in between the Lower Ganga canal and the Ganga river, the bar digram shows that anions and cations are low in concentration than Ganiwali and Kasganj.

Further, the diagram reveals that concentration of Na+K is low in case of Dinapur than the Calcium and Magnesium, while in all other samples the Na+K is higher than the other constituents of cation group. Similarly among the anions $HCO_3^- + CO_3^{--} > SO_4^{--} > Cl^-$.

STIFF'S DIAGRAM REPRESENTING THE ANALYSES OF GROUNDWATER QUALITY AT FOUR DIFFERENT PLACES

FIG.42



Pattern diagram

The pattern diagram first suggested by Stiff (1951) for representing chemical analysis by four parallel axis. The concentration of cations are plotted to the left of a vertical axis and anions to the right, all values are in milli-equivalents per litre. The resulting points when connected from an irregular polygonal pattern. The analysis of the four samples were plotted in pattern diagram (Fig. 42). It too represent similar situation as evident from bar diagram.

Trilinear diagram

Piper (1953) developed a form of trilinear diagram which is an effective tool in segregating analysis data for critical study with respect to sources of the dissolved constituents in groundwater, modification in character of a water as it passes through an area and related geochemical problems.

The Piper trilinear diagram combined three distinct field for plotting, two triangular fields at lower left and lower right respectively, and an intervening diamond-shaped field. All three fields have scales reading 100 parts (Fig. 43). In the triangular field at the lower left, the percentage reacting values of the three cation groups (Ca^{++}, Mg^{++}, Na^{+}) are plotted as single point according to conventional trilinear co-ordinates. The three anion groups (HCO_3^-, SO_4^{--} and Cl^-) are plotted likewise at the triangular field at the lower right. Thus, two points on the diagram one in each of triangular fields indicate the relative concentrations of the several dissolved constituents of a groundwater. The subtotal of all cations equivalents per million is taken as the 100 percent base for computing percentages reacting values of the several cation variables, likewise for the several anion variables. The central-diamond-shaped field is used to show the overall chemical character of the groundwater single point plotting, which is at intersection of rays projected from the plottings of cations and an ions. The position of this plotting indicates the relative composition of a groundwater in terms of cation-anion pairs that correspond to the four vertices of the field.

GROUNDWATER FACIES

The concept of groundwater facies was developed by Back (1961, 1966); Morgan and Winner (1962) and Seaber (1962).

The definition of hydrochemical facies is a paraphrase of the definition of facies as used by geologist; facies are identifiable parts of different nature belonging to any geneticaly related body or system. Hydrochemical facies are distinct zone that have cation and anion concentrations describable within defined composition categories (Freeze and Cherry, 1979). As water flow through an aquifer it assumes a diagnostic chemical composition as a result of interaction with the lithologic framework or geologic environments. According to Back (1961) the term hydrochemical facies is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of lithology, solution kinetics, and flow patterns of the aquifer (Back, 1966).

To designate hydrochemical facies of the study area the cations and anions percentages have been determined. These values were plotted on the classification diagram for anion and cation facies as suggested by Morgan and Winner (1962) and Back (1966).

The plot of chemical analysis, composition of the groundwater on the aforesaid diagram has brought out the following type of hydrochemical facies.

The majority of groundwater samples belong to Bicarbonate type and only few samples belong to No Dominant type class. Among the cation facies the water samples fall in class Sodium or Potassium type and No Dominant type, and only one sample fall in class Magnesium type.

The study shows that the groundwater of the study area belongs to an alkali-bicarbonate type.

TRACE ELEMENTS

Apart from the useful functions of the major ions the importance of the trace elements have recently been recognised which play a very important role in diet of humans and animals and the healthy growth of the plants.

The trace element like Fe, Zn, Cu, Pb, Cd, Cr, Sr, Mn and Li were determined in the water samples of the shallow and deep aquifers. The concentration of these elements were found more in water samples of shallow aquifers than of the deeper aquifers. The probable cause may be due to excessive use of fertilizers, Pesticides, herbicides, agricultural waste, besides house hold refuses and sewage disposals etc. The results of chemical analysis are given in (Appendix - IXA & IXB). The range of various trace elements are given below.

Iron

Occurs in most of the groundwater samples of the area and its concentration ranges between 0.03 to 1.92 ppm in shallow aquifer. While in deeper aquifer it varies between 0 to .346 ppm.

Lead

The concentration of lead ranges from 0.022 ppm to 0.8546 ppm in shallow aquifers while in deeper aquifers it ranges from 0 to 0.238 ppm. In shallow aquifer the concentration of lead is higher than the deeper aquifers.

Zinc

The concentration of zinc in the shallow groundwater samples varies from .011 to 0.484 ppm while in deeper aquifer it ranges from 0.013 to 0.099 ppm.

Copper

Concentration of copper ranges from 0.011 to 0.106 ppm in the shallow groundwater samples and in deeper aquifer it ranges between 0 to 0.042 ppm.

Cadmium

Cadmium concentration ranges between 0.0078 to 0.0425 ppm in the shallow groundwater and between 0.0081 to 0.0333 ppm in deeper groundwater samples.

Chromium (Cr^{+6})

The concentration Cr^{+6} ranges from 0.0290 to 0.1165 ppm and from 0.0097 to 0.065 ppm in shallow and deeper aquifer water samples respectively.

Manganese

The concentration of Manganese in the water collected from the shallow aquifer ranges from 0.013 to 0.760 ppm. In deeper aquifer water samples it ranges between 0.01 to 0.076 ppm.

Strontium

Strontium behave very much like calcium but its concentrations in the shallow aquifer samples varies from 0.008 to 2.078 ppm and deeper aquifer samples ranges between 0.007 to 0.994 ppm.

Lithium

Lithium concentration shows a range between 0.016 to 0.039 ppm in the shallow groundwater samples and in deeper aquifer sample it range between 0.007 to .035 ppm.

WATER QUALITY CRITERIA IN RELATION TO ITS USE

The term quality as applied to water embraces the combined physical, chemical and biological characteristic and is a dominant factor in determining the adequancy of any supply to satisfy the requirements of various water uses.

The quality of groundwater is a resultant of all processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged from wells or springs (Herman et al., 1978).

The interpretation of the chemical analysis is highly subjective matter and is not possible to have a single criteria that can have universal application. Therefore a certain accepted standard has been adopted while doing the interpretation of chemical analysis results of water in relation to its use. The main classes of uses are.

1. Domestic
2. Agricultural
3. Industrial

Water Quality for Domestic and Municipal Uses

Various organisation all over the world such as USPHA (1962), World Health Organisation (1975, 1984) and Indian Council of Medical Research (1975) have laid down certain guide lines for the evaluation of wate quality for domestic and Municipal supplies.

Table - 11: Range of concentration of various major and trace elements in shallow ground water samples and their comparison with W.H.O. (1984) and I.S.I. (1983) Drinking Water Standards.

S.No.	Constituents	Indian Standard Institute (1983)		World Health Organisation (1984)		Study Area
		Highest desirable Level	Maximum permissible Level	Highest desirable Level	Maximum permissible Level	
1.	pH	6.5-8.5	6.5-9.5	7-8.5	6.5-9.2	7.5-8.8
2.	Total Hardness	300	600	100	500	140-360
3.	Calcium	75	200	75	200	29.2-74
4.	Magnesium	30	100	-	150	14-72
5.	Sodium	-	-	-	-	-
6.	Chloride	250	1000	200	600	17.75-186
7.	Copper	0.05	1.5	0.05	15	0.011-0.106
8.	Iron	0.3	1.0	0.1	1.0	0.03-1.92
9.	Manganese	0.1	0.5	0.05	0.5	0.013-0.76
10.	Cadmium	0.01	No relaxation	-	0.01	0.0078-.0425
11.	Lead	0.1	"	-	0.1	0.022-0.8546
12.	Zinc	5	15	5	15	0.011-0.484
13.	Hexa vatent Chromium	0.05	No relaxation	-	-	0.0290-0.1165

These standards are based on two criteria (1) Presence of objectionable tastes, Odors or Colours (2) Presence of substances with adverse physiological effects. The primary aim of these guide lines is the protection of the public health and well beings of the mankind.

On the same guide line the concentration of vaious major and trace elements encountered in the water sample of the study area are compared with the drinking water standards of the World Health Organisation (1984) and Indian Council of Medical Research which are given in Table (11).

The Table & Appendix shows that the concentration of pH, EC, Total Dissolve Solids, Ca, Mg, Cl, Na and K are within the permissible limits of World Health Organisation (1984) and the Indian Council of Medical Research (1975). Hence, they can not cause any hazard to the public health in the study area. However, the concentration of certain trace elements like Fe, Pb, Cd, Cr, Mn has been encountered higher than their standard limit in drinking water. These trace elements are probably most harmful and insidious pollutants because of their biological, non-bio-degradable nature and their potential to cause adverse effects in human being at certain level of exposure and absorption. The harmful effects are linked to the accumulation in biological system even in their lowest form of development. Many workers have studied the quality of drinking water in relation to trace elements (Carun and Mc Cabe, 1975' Nori et al., 1975; Olwin, 1977; Schroeder and Kraemer, 1974).

These studies have indicated an association between water quality and mortality from cardiovascular and other chronic diseases. A significant positive correlation between mortality from various types of cancer and the concentration of trace metals in water supplies has also been described (Berg and Burbank, 1972; Sunderman, 1977). The water supply system is a major source of metals in drinking water (Craun and Mc Cabe, 1975). Corrision of distribution system and house hold plumbing also contributes to metal content of drinking water. The trace elements like Cd, Pb, Cu and Zn often occur in plumbing materials and have been found to leach into soft drinking water (Drinking Water and Health part I, 1977).

Various trace elements determined in groundwater samples are discussed below.

IRON

Iron is an essential element in human nutrition. Drinking water is not considered to be an important source, when administered parenterally. Iron is highly toxic element only when it crosses the permissible limit. Humans are usually well protected from oral over dose but children from 1 to 2 years of age are particularly vulnerable to iron toxicity from the ingestion of iron supplements that have been commercially prepared for adults)Fairbanks, et al., 1971). The presence of Fe can give rise to an astringent taste, discoloration, deposit of rust and could promote the growth of Iron bacteria.

W.H.O. (1984) has recommended the guide line value for iron as 0.3 mg/litre. The iron concentration in the water samples of shallow and deep aquifer ranges between 0.03 to 1.92 ppm and 0 to 0.346 ppm respectively.

A perusal of appendix indicates that most of the shallow aquifer sample show higher concentration of Fe than its permissible limit given by (W.H.O., 1984 and I.C.M.R., 1975). However, the concentration of iron in deeper aquifer water samples are lower than shallow aquifer samples. The higher concentration of iron may cause toxic effect on the public health.

Lead

Lead is a toxic metal and tends to accumulate in the tissues of man and animals, children and infants, fetuses in utero. The pregnant woman are most sensitive to environmental lead exposure (W.H.O., 1977), Synder et al., (1971) have described the effect of lead poisoning on man. Lead has been demonstrated to be extremely deleterious as related to haem-biosynthesis.

Chishobn (1971) and Goyer and Rhyne (1973) have reported that elevated blood lead disrupts the blood enzyme delta-amino levulinic acid dehydrates (ALAD) activity in human and can induce a reduction in haemoglobin.

Lead in high doses has been recognized for centuries as a cumulative general metabolic poison. Some of the symptoms of acute poisoning are tiredness, lassitude, Slight abdominal discomfort, irritability, anaemia and in the case of children, behavioural changes (W.H.O., 1984).

As per recommendation of (W.H.O., 1984, I.S.I., 1983) the highest desirable level of lead in drinking water is 0.1 mg/l. The water samples of shallow aquifer in the study shows the lead concentration in range of 0.02 to 0.85 while in water of the deeper aquifers the concentration of lead varies between 0 to 0.2380 mg/litre.

The table shows that the concentration of lead in shallow aquifer is generally high than the permissible limits through out the area. The maximum concentration of lead was recorded in the water sample at Kasganj town. The high concentration of lead in shallow aquifer water samples may cause health hazards to the inhabitants of the area.

Copper

Copper is an essential element in human metabolism(W.H.O., 1973) and is considered to be non-toxic for man at 0.05 mg/l level, in drinking water. The greatest danger of toxicity arises when children consume acidic beverages that have been in contact with copper container or valves (Food and Drug Administration, 1975). However, few patients with wilson's disease (hepatolenticular degeneration) were adversly affected by the estimated average intake of copper (Schienberg and Sternleb 1965).

The concentration of copper in the water samples from the shallow aquifers ranges between 0.011 to 0.106 while in deeper aquifers water samples it ranges between 0.002 to 0.042 ppm. The analytical result (Appedix - IXA & IXB) shows that the concentration of copper is well within the permissible limit of W.H.O., (1984) and ISI, (1983).

Cadmium

Cadmium is one of the most toxic to man and animals (Friberg et al., 1974) Cadmium gets accumulated and is retained mainly in the liver and kidney, thus causing pathological changes of the hepatocytes of the liver as well as kidney, tubules and glomerular changes (Itokawa et al., 1974; Colucci et al., 1975).

The health aspects of cadmium have been reviewed extensively by several workers (Fleisher, et al. 1974; Friberg et al., 1974; Webb, 1975; W.H.O., 1977). Among the general population ingestion of food and fluids that have been contaminated with cadmium resulted in acute gastrointestinal disturbances such as nausea, vomiting, abdominal pain, diarrhoea etc.

Moreover, the most common abnormality from chronic cadmium exposure involves renal toxicity characterized by proteinurea. Other renal disturbances of renal tubular function include glycosuria, amino acid urea decreases the urine concentrating ability, and abnormalities in renal processing of uric acid, calcium and phosphorus (Drinking water and Health Vol. 3, 1980).

Several epidemiological surveys have suggested that there is an increased incidence of prostate cancer in cadmium workers as compared to general population. The recommended permissible limit of cadmium in drinking water by (W.H.O., 1984 and I.S.I., 1983) is 0.01 ppm. The cadmium level detected in the shallow groundwater of the study area ranges between 0.0078 to 0.0425 ppm while in the deeper aquifer water samples the concentration of cadmium ranges from 0.0081 to 0.0333 ppm. The analytical results show that the concentration of cadmium in the shallow groundwater is slightly higher than the permissible limit while in the deeper aquifer water samples the level is well within the limits.

The higher concentration of cadmium in the shallow ground water may prove toxic to the inhabitants of the area.

Chromium

Because of the low solubility of chromium, generally, the levels found in water is usually low (9.7 ug/litre) National Academy of Science, (1974). Trivalent chromium rarely occurs in drinking water. Most water borne chromium is in the hexavalent form. Hexavalent chromium is much more toxic than trivalent chromium but has no nutritional value. Hexavalent chromium may be absorbed through the skin and by inhalation and corrosion. Sign of toxicity by these compounds include hemorrhage of the gastro inntestinal tract after ingestion, ulceration of the nasal septum and cancer of respiratory tract from inhalation and cutaneous injury upon dermal exposure (National Academy of Science, 1974).

The maximum permissible limit of Cr^{+6} in drinking water is 0.05 mg/l (W.H.O., 1984) is less than no-observed health effect level. The chromium concentration in the shallow groundwater of the study area varies from 0.029 to 0.11165 ppm. In most of the water samples the concentration of chromium is within the permissible limits except at few places where slightly higher range of chromium has been encountered. However, in deep water samples the concentration chromium ranges between 0.0097 to .065 ppm which is well with in the permissible limits.

Manganese

The concentration of Manganese ranges from 0.013 to 0.76 ppm in shallow groundwater samples of the study area while in deeper aquifer samples Manganese concentration varies between 0.01 to 0.076 ppm. At places the manganese concentration is higher than its permissible limit 0.05 ppm as recommended by (W.H.O., 1984). Higher concentration of Manganese may cause neurological syndrome, resembling Manganese encephalopathy (Anon., 1977).

Zinc

Zinc is an essential and beneficial element in human metabolism. The daily requirement of pre-school aged children is 0.3 mg Zn/kg body weight. The daily adult human intake average is 0 to 15 mg/kg. The zinc deficiency in children leads to the growth retardation.

Water containing Zinc at concentration in excess of 5.0 mg/litre has an undesirably astringent taste and may be opalescent, developing a greasy film on boiling. (World Health Organisation ,1984).

The concentration of zinc in the groundwater sample of shallow aquifer ranges from 0.011 to 0.484 ppm while in deeper aquifer it ranges from 0.013 to 0.099 ppm which is well within the permissible limit of (W.H.O., 1984).

WATER QUALITY CRITERIA FOR IRRIGATION

Water quality criteria for irrigation is a complex subject, because growth of particular crop depends on many factors and not merely on the chemistry of irrigation water.

However, factors to be considered in evaluating the usefulness of groundwater for irrigation are the total concentration of dissolved solids, the concentration of individual constituents, the relative proportion of some constituents, the nature and composition of the soil and sub-soil, the topography of land, the position of water table, the amounts of groundwater used and method of applying, it, the type of crop grown and the climate of the area and method of crop management (Walton, 1970).

Irrigational Specification

Various specifications have been proposed from time to time by different workers including Asgar et al. (1936) Kelley et al.

(1940); Wilcox (1955); Eaton (1950); USSLS (1954); Ramamorthy (1964); FWPCA (1968); EPA (1973); Ayers an Branson (1975) and Ayers and Wastcot (1976) for evaluating suitability of natural water for irrigation of crops.

In most of the specifications, the suitability of natural waters for irrigation has been evaluated on presumption that the water will be used under average conditions with respect to soil characteristics, efficiency of sub-surface drainage, amount of water used and method of applying it, type of crops and climatic characters of the area.

In order to study the suitability of groundwater in the Ganga-Kali sub-basin for agricultural uses, the Electrical conductivity, relative proportion of sodium to other cations, residual carbonate and concentration of certain specific elements were analysed and the data obtained from the chemical analysis of groundwater samples were processed and interpreted on the established guide lines proposed by various scientist of the discipline.

Salinity And Sodium Hazard

It is well established fact that crop production or even the germination of seed is reduced when excessive accumulation of salt exists on agricultural soil. Irrigation water is one of the major contributor of soluble salts to the soil, in addition to those already present. Therefore, irrigation water play a major role in agriculture practices.

Among the major hazards to crop by irrigation water are salinity and sodium hazards. A soil high in exchangeable sodium is very undesirable for agriculture as it causes flocculation resulting into the formation of a relatively impermeable crust (Hem, 1959) which lowers the fertility of the soil.

The interpretation of water quality suitable for irrigation purposes are given by Richard et al. (1954). They put forward a diagram on the salinity of water. Electrical Conductivity (E.C.) has been taken as an index of salinity hazards and sodium Adsorption Ratio (SAR) as an index of sodium hazards. The SAR is defined as

$$SAR = \frac{Na}{\sqrt{\dfrac{Ca + Mg}{2}}}$$

where concentration of cations are expressed in meq/litre.

The quality classification of irrigation water is given in table.

Table -12: Quality classification of irrigation water (After USSL 1954)

Water	Salinity Hazard EC in Micro mhos/cm at 25°C	Alkali S.A.R.	R.S.C. in meq/L
Excellent	250	upto 10	$\ll$ 1.25
Good	250 - 750	10 - 18	$<$ 1.25
Fair	750 - 2250	18 - 26	1.25 - 2.5
Poor	2250	26	$>$ 2.50

The SAR have been calculated and data obtained is compared and plotted on the USSL (1954) diagram (Fig. 44). The diagram reveals that the most of water samples fall in class C_1-S_1 and C_2-S_1 and accordingly the groundwater in the area is very much suitable for irrigation as it is free from sodium or salinity hazards.

Eaton (1950) suggested that water having carbonate and bicarbonate ions in excess of calcium plus mangnesium will lead to much greater alkali formation than is indicated by its SAR and thereby decreasing soil permeability. The carbonate and bicarbonate hazards on water quality can be determined in terms of Residual Sodium Carbonate (RSC) which is defined by the following equation

$$RSC = (CO_3^{--} + HCO_3^{--}) - (Ca^{++} + Mg^{++})$$

where all the concentrations are expressed in epm. Water with RSC below 1.25 meq/l is good, 1.25 - 2.5 meq/L is marginal and above 2.5 meq/L is not suitable for irrigation purposes.

The Residual Sodium carbonate of water sample have been determined and the results obtained are given in (Appendix - VIIIB). A perusal of appendix shows that in most of the sample the RSC is less than one but at few places higher values have also been determined. In general the water is suitable for irrigation in terms of RSC too.

Wilcox (1955) has proposed another classification scheme for rating irrigation water on the basis of electrical conductance, soluble sodium percent and boron concentration. The sodium percent is calculated by the following formula

$$Na\ \% = \frac{(Na + K) \times 100}{Ca + Mg + Na + K}$$

where all the concentration are expressed in Epm. The following classification is given by Wilcox (1955).

Table-13: Quality classification of water for irrigation.

Water	Na %	EC umhos
Excellent	$<$ 20	$<$ 250
Good	20 - 40	250 - 270
Permissible	40 - 60	750 - 2000
Doubtful	60 - 80	2000 - 3000
Unsuitable	$>$ 80	$>$ 3000

The sodium percent has been calculated on the basis of Wilcox formula. The data obtained are given in appendix and plotted on Wilcox diagram (Fig. 45). The diagram reveals that 99% water samples fall in class excellent and good to permissible except one water sample from Charra village which fall in class permissible to doubtful. Hence the groundwater quality of the study area is by all standard suitable for irrigation.

Besides, the useful function of major ions, role of trace elements in the proper growth of the plants has attained great emphasis in recent years. They have been found profoundly beneficial to crops for growth of plants at different stages. Federal water Pollution control Federation, U.S.A. (1968) and Ayers and Branson (1975) put forward tolerance limit for irrigation water and suggested proper interpretation of analytical data; micronutrients like Cu, Zn, Fe were determined in water samples. The results obtained were compared with standard limit (F.W.P.C.F., 1968; Ayers and Branson, 1975).

The concentration of the above mentioned trace elements in groundwater of the area are well with in the permissible limits from the aforesaid discussion and interpretation of the chemical analyses data of groundwater it can safely be concluded that by all the standards, the groundwater quality of the Ganga-Kali sub-basin is highly suitable for irrigation.

SURFACE WATER QUALITY

In order to study the surface water quality and its relation with groundwater, samples for major and trace element studies were collected from different sampling stations established on the river Ganga, Kali and the Lower Ganga canal later on these samples were

Table -15: Range of concentration of various major and trace element in surface water samples and their comparison with W.H.O. (1984) and I.S.I. (1983) drinking water standards.

Constituents	Indian Standards Institute (1983)		W.H.O. (1984)		Range of concentration in surface water bodies in ppm		
	Highest desired level mg/l	Maximum permissible level mg/l	Highest desired level	Maximum permissible level	River Ganga	River Kali	Lower Ganga Canal
1. pH	6.5-8.5	6.5-9.2	7 -8.5	6.5-9.2	7.51 to 8	7.7 to 7.82	7.6 to 8
2. Total Hardness	300	600	100	500	85 - 105	144 - 740	110 - 117
3. Calcium	75	200	75	200	25 - 28	56 - 240	31.8-32.01
4. Magnesium	30	100	-	150	5 - 10.18	25 -108	8.5 - 10.00
5. Chloride	250	1000	200	600	14 - 24	38 - 68	30.16-38.56
6. Copper	0.05	1.5	0.05	1.5	0.06-0.4	0.126-0.426	0.421-0.5
7. Iron	0.3	1.0	0.1	1.0	58 -1.82	0.095-2.44	0.326-0.346
8. Manganese	0.1	0.5	0:05	0.5	0.652-0.674	0.012-0.203	0.068-0.09
9. Cadmium	0.01	No relaxation	-	0.01	0.005-0.07	0.003-0.029	0.001-0.041
10. Lead	0.01	"	-	0.01	0.164-0.185	0.007-9.148	0.09-0.1
11. Zinc	5	15	5	15	0.022-0.094		
12. Chromium(Cr^{+6})	0.05	No relaxation	-	-	0.038-0.04	0.004-0.162	0.05-

chemically analysed. The chemical analysis data are appended as (annexure - XIA & B).

Table 15 shows the comparison of various constituents detected in the Ganga and Kali rivers and Lower Ganga canal waters with W.H.O. (1984) and I.S.I. (1983) drinking water standards. A perusal of table shows that pH ranges from 7.5 to 8, 7.5 to 7.9 and 7.6 to 8 and E.C. varies between 153 to 210, 471 to 510 and 127 to 140 umhos/cm at 25°C in the water samples of the river Ganga, Kali and Lower Ganga canal respectively, showing alkaline nature of these water. Further, the result of the chemical analysis reveal that the values of cations and anions are low in the Ganga and Lower Ganga canal than the groundwater samples. The Kali river water shows higher values of cations and anions than the Ganga river water samples. But they are well within the permissible limit of W.H.O. (1984) drinking water standards, except one water sample collected close to Bidhari village which shows higher values of Ca^{++} and Mg^{++}.

However, the analytical results show that the concentration of certain trace elements like Fe, Mn, Cd, Pb and Cr^{+6} are higher than their permissible limit for drinking purposes in water samples of the river Ganga and Kali.

However, these waters are suitable for irrigation uses. As regards higher levels of toxic trace metals it can be said that it is caused due to the municipal, industrial, discharges into these rivers. Suitable measures as suggested by U.P. State Pollution Control Board, is to make it obligatory on the municipalties and industries to discharge their effluents into these river only after proper treatment.

SUMMARY AND CONCLUSION

The Ganga basin forms one of the prominent physiographic units of India. As regards its origin various views are there. Most recent view is that it was formed as a result of sagging of earth crust that intervened between mobile belt of the Himalayas and comparatively stable Peninsular shield which was latter filled with the sediments eroded from newly risen Himalayas and the Peninsula. Another view considers Indo-Gangetic plain a peripheral foreland basin formed as a result of continent-continent collision between Indian and Asian plates.

The unconsolidated-Quaternary sediments vary in thickness from less than 6 meters at its southern margin to 6000 meters close to the Himalayan foot hills. A large stretch of the alluvial tract is occupied by the state of Uttar Pradesh, which is hydrogeologically divided into the following zones viz. Intermontane valley, Piedmont zone or Bhabar, Artesian or Tarai belt zone, central Ganga plain and southern marginal plain. These zones are the great repository of groundwater and hold most potential aquifers in the state. In the intermontane valley which consists of bouldary strata, groundwater occurs under water table condition but the water table is very deep. The piedmont zone stretches parallel to the Himalayan foot hills due south upto the spring line. It is formed due to coalesence of fan deposits comprising bouldery strata mixed with sand which is highly transmissive, has deep water table and forms a recharge areas for the deeper aquifers in Tarai and the central Ganga plain. The spring line defines the southern limit of Bhabar zone and also forms the northern limit of Tarai zone. The spring line is the resultant of the aquifers cutting the land surface where from water continuously oozes out. That is why it is called wetland or Tarai zone. The southern limit of this zone imperceptibly merges into central Ganga plain. The belt is characterized by pre-dominant clayey sediments with intercalated beds of sand and gravels with frequent free flowing conditions.

The southern limit of central Ganga plain is fixed by Yamuna and its confluence with Ganga stretching from West-North West to East South East. This sub-zone covers major part of the state encompassing the Ganga-Yamuna interfluves. The area of investigation which stretches over 1340 sq kilometer is a part of the Ganga-Kali sub-basin of the great central ganga plain. It falls under the subtropical climatic zone, with hot summer (40-45°C) and chilly winter (4-6°C). The monsoon breaks in second week of June and ends in September. The mean annual rainfall as computed for the period 1901 to 1989 is 754.12 mm.

Based on physiography and hydrogeological condition it has been divided into three physiographic units viz.(I).Low valley of the Ganga river (II) Eastern upland and (III) Nim Kali interfluves. Geomorphologically, there are three distinct planation surfaces (To, T1, T2) which have developed in response to the changing climate and sea level fluctuations during late Quaternary. The braided stream character and fine sand size of the active channel of the present day Ganga river is To surface. This surface is made up of few active channels and channel bars. T1 surface is located 5-10 m above To surface which shows many meander scars and a prominent meander scroll. T2 surface is upland surface. This surface shows presence of many abandoned drainages and abandoned meandering channel belts. The study shows that during the last 25000 years the Ganga river underwent a distinct change from meandering type to present day braided type consequent to decrease in water budget and increase in sediment load.

Consequent to the oil and water well drillings the subsurface topography beneath the Quaternary alluvium is found to consist of alternate spurs and depressions. The study area lies on Kaganj-Tanakpur spur. The geological cross-sections reveal that on the eroded surface of the Archean basement (Bundelkhand granite) upper Vindhyans were deposited during the upper proterozoic era. Thereafter they underwent a post Vindhyan faulting and erosion since Cambrian to Lower Miocene. During this span of time encompassing about 500 million years, the Vindhyan topography was reduced to almost peneplain and on these eroded surfaces of the upper Vindhyans, Neogene Siwaliks were deposited which was latter on followed by the deposition of Quaternary sediments. This Quaternary deposits healed up earlier depressions through rapid sedimentation giving thereby a broad monotonous level expanses which is the present Ganga basin. Further, the thickness of Vindhyans, Neogene siwaliks and Quaternary sediments gradually increased due north and attains their maximum thickness close to the Himalayan foothills.

The river Ganga-the trunk stream and its numerous tributaries have given rise to numbers of sand bodies such as channel, flood plain and back swamp deposits, generating thereby various aquifer types of differing dimensions through their varying flow regimes during the past 0.6 Ma. The fence diagram and the various hydrogeological cross-section depict that in all there occurs two to three tier aquifer system down to 140 metre b.g.l. These aquifers finally merge with each other and behave as single bodied aquifer system. Alluvium with its sizeable thickness of about 360 metres comprises clay silt and sands of various grades, calcareous concretion and gravel etc., in varying proportions. The beds are generally lenticular and there are rapid alteration and gradations between granular and clayey materials particularly in south western part of the area.

The granular zone attains its maximum thickness in the eastern part of the area which gradually decreases due west. Many more aquifers possibly occur below 150 metre down to 360 metre depth at which the Quaternary deposits unconformably overlies the Neogene siwaliks which in turn overlies the eroded and uneven surface of upper Vindhyan limestone of upper Proterozoic age. The near surface groundwater occurs under water table condition and depth to water varies between 2 to 16 metres below ground level. While deeper aquifer occur under confined conditions. The piezometric level of deeper aquifer ranges between 3 to 12 meter below ground level. The hydrogeologic parameters like specific capacity, transmissivity and hydraulic conductivity determined by the discharge and draw-down data of deep tubewells ranged between 379.4 to 2272.8 m/day 462.8 to 2272.6 m^2/day and 13 to 698 m/day respectively.

A perusal of pre-monsoon (1988-89) depth to water maps reveal that in western part water level is generally deep which ranged between 8 to 16 metres below ground level. The shallow water table leading to the swampy conditions during post-monsoon period (November, 1988-89) was observed as a characteristic feature of low valleys of the Ganga and in the areas adjacent to lower and upper Ganga canals. In these tracts the water level during (June 1988-89) ranged between 1.8 to 4 metre and 1.6 to 4 metre below ground level respectively. The shallow water level in this tract was because of influent seepage through the canal bed into the shallow aquifers below these canal.

The water table fluctuation revealed a rising trend of varying degree in water level throughout the basin during (1988-89). In 1988 water level fluctuation ranged between 0.5 to 2 metres. The study shows that 35% of wells show fluctuation in the range of 0.5 to 1 m, 33.12% well shows fluctuation in the range 1 to 1.5 m and only, 14.37% of the area recorded the fluctuation $<$0.5 meters. This high fluctuation in water level during 1988 is attributed to the heavy rainfall while in 1989 the fluctuation was comparatively of lesser degree due to the deficient rainfall.

Altitude of water table in pre-monsoon ranged between 179 metre in North west to 162 metres in, South east above the mean sea level. The master slope of water table was observed due South east following the general topography of the area. In eastern part, the slope of the water table was towards east parallel to the general slope of the ground. Hydraulic gradient is steeper in the east and south close to the Ganga and Kali rivers than the central part of the basin, indicating that the sediments are finer and have low permeability. Further, the contour behaviour shows that both the Ganga and Kali rivers are effluent in nature except close to the Atrauli area where the Kali river behaves as an influent stream. This reversal of hydraulic gradient is the resultant effect of the excessive withdrawal of the groundwater in the area.

The post-monsoon contours show almost similar behaviour except that contours are found to displace by the higher values. Piezometric contours also exhibit pattern similar to that of water table contours but in the north eastern side the piezometric head is higher than the water table by 2 meters. The similarity of water table and piezometric level maps is an indicative of the common source of recharge.

Rainfall is the main source of groundwater recharge. Besides canal seepage and irrigation return flow form the secondary sources of groundwater recharge. The hydrographs of the observation wells show that the water level variation is cyclic and sinusoidal as a function of time and space. It shows that the response of water level to rainfall and drought is reasonably quick in space and time. The ascent of level is also greatly affected by the intensity, duration and distribution of the rainfall in the area.

Further, it is seen from the hydrographs that there was progressive decline in water level in Nim-Kali interfluves. The average rate of decline is recorded as 0.34 m/year. The hydrographs falling in Nim-Ganga interfluves do not show any significant change in the behavour of water level. This is because of the significant recharge of the shallow aquifers through canal networks in the Ganga-Nim interfluves.

The pumping test data analysis results reveal that the transmissivity and storativity/specific yield values determined at Paharipur and Danpur range between 2059.6 m^2/day to 528.12 m^2/day and 8.95 to 7.75 x 10^{-4} respectively. The hydraulic conductivity values ranges between 37.7 m/day to 72.88 m/day. The pumping test data analysis further show that the upper aquifers are unconfined in nature while the deeper aquifer are under confined conditions.

In order to achieve effective planning and systematic exploitation of groundwater resources, assessment of groundwater reserves was also attempted. Assessment studies reveal that net groundwater recharge in the Ganga-Kali sub-basin is 326.97 M.C.M.

The net draft is 157.6 M.C.M., leaving a balance of 169.4 M.C.M. as the utilizable groundwater resource for the future development.

Following the ARDC Norms, the stage of groundwater development in the Ganga-Kali sub-basin was estimated which shows that only 48.2% groundwater development has taken place and accordingly basin falls under the 'white' category.

In view of the fact that only 48.2% of groundwater development has been done so far there is a large groundwater surplus for further development in the basin which can be utilized through the construction of atleast 588 deep tubewell with a unit draft of 0.17 M.C.M., with a well spacing of 237 meters and with possible drawdown of 6.5 to 7 meters. Besides it 3670 shallow tubewells with a unit draft of 0.0188 M.C.M. with a well spacing of 150 meters may also be constructed.

Water samples collected from observation well network, shallow and deep tubewells and also from rivers and canals were analysed for various constituents affecting the quality of water and its suitability for drinking and irrigational purposes was studied. The results of chemical analysis data show that the groundwater in the basin belong to Bicarbonate facies of anion group and Na-K type in cation facies. With few exceptions generally the groundwater is potable, hard alkaline in reaction and moderately mineralised and alkaline bicarbonate type.

Trace element studies show that the concentration of heavy toxic metals like Cd, Pb, Cr^{+6} in the shallow aquifer water is more than their permissible limits which may entail various health hazards to the inhabitants of the area. However, the concentration of these trace elements were generally found well with in the permissible limit in deeper aquifer groundwater samples. In general, the groundwater of the basin is suitable for drinking and irrigational purposes.

Surface water sample analysis reveal that the concentration of major ions is generally lower than the groundwater in the basin. However, the concentration of trace elements in water sample of the Ganga and Kali river are much higher than their permissible limits. The higher concentration of the toxic heavy metals may be due to the huge discharge of the waste effluents from the cities located at their banks.

In the years to come when the area will reach its optimum development sometime in 21st century, the major problem will be of depleting aquifers in Nim-Kali upland due to heavy withdrawal caused by rising population, expanding agriculture and escalating industrialisation. It is therefore necessary to continue monitoring of water level as well as re-appraisal of groundwater resources, for proper understanding of groundwater behaviour vis-a-vis the pace of groundwater development in the area. In view of the declining water levels consequent to the excessive withdrawal from the shallow aquifer, it is suggested that further exploitation of groundwater from the shallow aquifer should be restricted and it should be supplemented with the introduction of canal irrigation which is conspicuously absent in the area. Further, the groundwater development in the area is restricted upto depth of 150 meeters only while the thickness of alluvium is 360 meters. There are more potential aquifers in the area down to 360 m. Hence these aquifers should first be thoroughly explored and quantitatively and qualitatively assessed before any development is attempted to meet the future demand.

Conjuctive use of surface and groundwater resources is the optimal method of obtaining the maximum possible water development in the Ganga-Kali sub-basin. This is true to the dual situation as prevailing in the area i.e. on the Ganga-Nim upland that there is large scale water logging and consequent soil salinization while there is declining water-table in Nim-Kali upland. If redressal of former lies in checking the canal seepage through polythene sheet lining to arrrest water logging and soil salinization, where artificial recharge through the canal networks will contain the declinning trend of water level.

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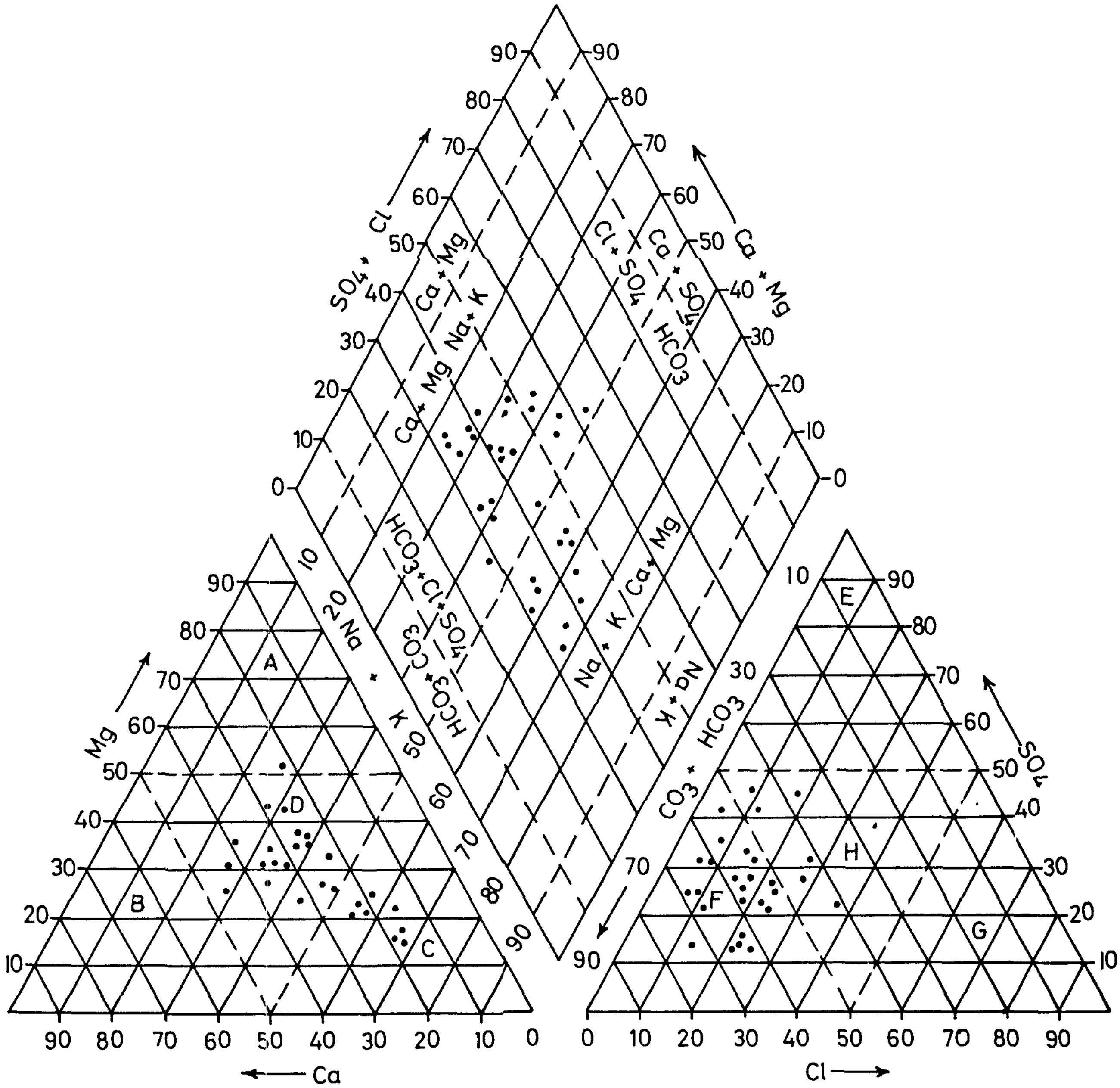
TRILINEAR DIAGRAM OF WELL WATER

FIG.43



Cations Facies

A. Magnisium type
B. Calcium type
C. Sodium or Potassium type
D. No Dominent type

Anions Facies

E. Sulphate type
F. Bicorbonate type
G. Chloride type
H. No Dominent type

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APPENDICES

APPENDIX - I (A)

RAINFALL DATA ANALYSIS OF ATRAULI RAIN GAUGE STATION

THE MEAN OF 89 YEARS OF RAINFALL = 755.06

THE STANDARD DEVIATION = 250.359

THE COEFFICIENT OF VARIATION = 33.1809

S.No.	YEAR	ANNUAL RAINFALL	DEPARTURE	CUMULATIVE DEPARTURE	$(X-\bar{X})$	$(X-\bar{X})^2$
1.	1901	358.00	-0.53	-0.53	-397.06	157657.17
2.	1902	474.00	-0.37	-0.90	-281.06	78995.10
3.	1903	532.00	-0.30	-1.19	-223.06	49756.06
4.	1904	480.00	-0.36	-1.56	-275.06	75658.38
5.	1905	383.00	-0.49	-2.05	-372.06	138429.14
6.	1906	980.00	0.30	-1.75	224.94	50597.70
7.	1907	570.00	-0.25	-2.00	-185.06	34247.45
8.	1908	525.00	-0.30	-2.30	-230.06	52927.91
9.	1909	660.00	-0.13	-2.43	-95.06	9036.53
10.	1910	750.00	-0.01	-2.44	-5.06	25.61
11.	1911	740.00	-0.02	-2.45	-15.06	226.82
12.	1912	420.00	-0.44	-2.90	-335.06	112265.65
13.	1913	605.00	-0.21	-3.10	-150.06	22518.21
14.	1914	717.00	-0.01	-3.15	-38.06	1448.61
15.	1915	540.00	-0.21	-3.43	-215.06	46251.09
16.	1916	1120.00	0.41	-2.95	364.94	133180.72
17.	1917	835.0	0.11	-2.84	79.94	6390.30
18.	1918	380.00	-0.50	-3.34	-375.06	140670.50
19.	1919	860.00	0.14	-3.20	104.94	11012.26
20.	1920	460.00	-0.39	-3.59	-295.06	87060.80
21.	1921	1170.00	0.55	-3.04	414.94	172174.66
22.	1922	910.00	0.21	-2.84	154.94	24006.20
23.	1923	640.00	-0.15	-2.99	-115.06	13238.96
24.	1924	840.00	0.11	-2.88	84.94	7214.69
25.	1925	670.00	-0.11	-2.99	-85.06	7235.32
26.	1926	640.00	-0.15	-3.14	-115.06	13238.96
27.	1927	900.00	0.19	-2.95	144.94	21007.41
28.	1928	570.00	-0.25	-3.20	-185.06	34247.45
29.	1929	410.00	-0.46	-3.65	-345.06	119066.87
30.	1930	450.00	-0.40	-4.06	-305.06	93062.02
31.	1931	600.00	-0.21	-4.26	-155.06	24043.81
32.	1932	560.00	-0.20	-4.52	-195.06	38048.66
33.	1933	1300.00	0.72	-3.80	544.94	296958.88
34.	1934	830.00	0.10	-3.70	74.94	5615.90

1	2	3	4	5	6	7
35.	1935	730.00	-0.03	-3.73	-25.06	628.04
36.	1936	780.00	0.03	-3.70	24.94	621.97
37.	1937	580.00	-0.23	-3.93	-175.06	30646.24
38.	1938	510.00	-0.32	-4.26	-245.06	60054.73
39.	1939	900.00	0.19	-4.06	144.94	21007.41
40.	1940	800.00	0.06	-4.00	44.94	2019.54
41.	1941	350.00	-0.54	-4.54	-405.06	164074.14
42.	1942	1140.00	0.51	-4.03	384.94	148178.28
43.	1943	700.00	-0.07	-4.10	-55.06	3031.68
44.	1944	610.00	-0.19	-4.30	-145.06	21042.60
45.	1945	800.00	0.06	-4.24	44.94	2019.54
46.	1946	790.00	0.05	-4.19	34.94	1220.76
47.	1947	780.00	0.03	-4.16	24.94	621.97
48.	1948	820.00	0.09	-4.07	64.94	4217.12
49.	1949	718.00	0.05	-4.12	-37.06	1373.49
50.	1950	900.00	0.19	-3.93	144.94	21007.41
51.	1951	905.00	0.20	-3.73	149.94	22481.80
52.	1952	744.00	0.01	-3.74	-11.06	122.34
53.	1953	442.00	-0.41	-4.16	-313.06	98006.98
54.	1954	911.00	0.21	-3.95	155.94	24317.07
55.	1965	1164.00	0.54	-3.41	408.94	167231.38
56.	1956	842.00	0.12	-3.30	86.94	7558.45
57.	1957	75.00	-0.90	-4.20	-680.06	462482.50
58.	1958	902.00	0.19	-4.00	146.94	21591.17
59.	1959	513.00	-0.32	-4.32	-242.06	58593.37
60.	1960	769.00	0.02	-4.30	13.94	194.30
61.	1961	885.0	0.17	-4.13	129.94	16884.23
62.	1962	695.00	-0.08	-4.21	-60.06	3607.28
63.	1963	928.00	0.23	-3.98	172.94	29908.01
64.	1964	905.00	0.20	-3.78	149.94	22481.80
65.	1965	696.00	-0.08	-3.86	-59.06	3488.16
66.	1966	574.00	-0.24	-4.10	-181.06	32782.96
67.	1967	1224.00	0.62	-3.48	468.94	219904.09
68.	1968	696.00	-0.08	-3.56	-59.06	3488.16
69.	1969	997.00	0.32	-3.24	241.94	58534.64
70.	1970	964.00	0.28	-2.96	208.94	43655.64
71.	1971	1092.00	0.45	-2.52	336.94	113528.11
72.	1972	1006.00	0.33	-2.18	250.94	62970.55
73.	1973	973.00	0.29	-1.89	217.94	47497.55
74.	1974	1120.00	0.48	-1.41	364.94	133180.72
75.	1975	949.00	0.26	-1.15	193.94	37612.46

1	2	3	4	5	6	7
76.	1976	973.00	0.29	-0.87	217.94	47497.55
77.	1977	1291.00	0.71	-0.16	535.94	287230.97
78.	1978	997.00	0.32	0.16	241.94	58534.64
79.	1979	334.00	-0.56	-0.39	-421.06	177292.09
80.	1980	762.00	0.01	-0.38	6.94	48.15
81.	1981	495.00	-0.34	-0.73	-260.06	67631.55
82.	1982	939.00	0.24	-0.48	183.94	33833.68
83.	1983	1402.00	0.86	0.37	646.94	418530.50
84.	1984	660.00	-0.13	0.25	-95.06	9036.53
85.	1985	765.00	0.01	0.26	9.94	98.79
86.	1986	744.00	-0.01	0.24	-11.06	122.34
87.	1987	307.30	-0.59	-0.35	-447.76	200489.63
88.	1988	892.10	0.18	-0.17	137.04	18779.77
89.	1989	881.00	0.17	0.00	125.94	15860.71

DATA SOURCE : Regional Meteriological Centre, New Delhi.

APPENDIX I (B)

RAIN FALL DATA ANALYSIS OF KASGANJ RAIN GAUGE STATION

THE MEAN OF 89 YEARS OF RAIN FALL = 753.19

THE STANDARD DEVIATION = 222.4385

THE COEFFICIENT OF VARIATION = 29.9311

S.No.	YEAR	ANNUAL RAINFALL	DEPARTURE	CUMMULATIVE DEPARTURE	$(X-\bar{X})$	$(X-\bar{X})^2$
1.	1901	656.31	-0.13	-0.13	-96.99	9386.05
2.	1902	494.27	-0.34	-0.47	-258.92	67040.43
3.	1903	851.63	0.13	-0.34	98.44	9690.11
4.	1904	979.07	0.30	-0.04	225.88	51021.03
5.	1905	328.12	-0.56	-0.61	-425.07	180685.91
6.	1906	901.05	0.20	-0.41	147.86	21862.09
7.	1907	554.00	-0.26	-0.67	-199.19	39677.31
8.	1908	593.57	-0.21	-0.89	-159.62	25479.07
9.	1909	824.49	0.09	-0.79	71.30	5083.45
10.	1910	571.20	-0.24	-1.03	-181.99	33120.96
11.	1911	584.67	-0.22	-1.26	-168.52	28399.55
12.	1912	528.52	-0.30	-1.56	-224.67	50477.34
13.	1913	411.73	-0.45	-2.01	-341.46	116596.05
14.	1914	760.44	0.01	-2.00	7.25	52.54
15.	1915	605.50	-0.20	-2.20	-147.69	21812.82
16.	1916	1046.96	0.39	-1.81	293.77	86299.82
17.	1917	1072.76	0.42	-1.38	319.57	102123.94
18.	1918	208.00	-0.72	-2.10	-545.19	297233.94
19.	1919	800.57	0.06	-2.04	47.38	2244.71
20.	1920	649.45	-0.14	-2.18	-103.74	10762.33
21.	1921	1183.56	0.57	-1.61	430.37	185216.97
22.	1922	1143.43	0.52	-1.09	390.24	152286.02
23.	1923	553.40	-0.27	-1.36	-199.97	39916.70
24.	1924	889.80	0.18	-1.17	136.61	18661.84
25.	1925	740.64	-0.02	-1.19	-12.55	157.54
26.	1926	899.90	0.19	-1.00	146.71	21523.35
27.	1927	803.86	0.07	-0.93	50.67	2567.28
28.	1928	391.07	-0.48	-1.41	-362.12	131132.08
29.	1929	696.40	-0.08	-1.48	-56.79	3225.29
30.	1930	703.00	-0.07	-1.55	-50.19	2519.20
31.	1931	774.42	0.03	-1.52	21.23	450.64
32.	1932	383.70	-0.49	-2.10	-369.49	136524.08
33.	1933	892.59	0.19	-1.83	139.40	19431.91
34.	1934	763.20	0.01	-1.82	10.01	100.17

1	2	3	4	5	6	7
35.	1935	516.63	-0.31	-2.13	236.56	55961.41
36.	1936	1180.52	0.57	-1.56	427.33	182609.53
37.	1937	621.00	-0.18	-1.74	-132.19	17474.63
38.	1938	452.88	-0.40	-2.14	-300.31	90187.09
39.	1939	717.76	-0.05	-2.18	-35.43	1255.40
40.	1940	853.44	0.13	-2.05	100.25	10049.73
41.	1941	466.00	-0.38	-2.43	-287.19	82479.05
42.	1942	866.90	0.15	-2.28	113.71	12929.59
43.	1943	962.90	0.28	-2.00	209.71	43977.60
44.	1944	384.50	-0.49	-2.49	-368.69	135933.53
45.	1945	768.00	0.02	-2.47	14.81	219.29
46.	1946	884.93	0.17	-2.30	131.74	17354.99
47.	1947	491.50	-0.35	-2.64	-261.69	68482.52
48.	1948	724.10	-0.04	-2.68	-29.09	846.33
49.	1949	969.20	0.29	-2.40	216.01	46659.61
50.	1950	769.00	0.02	-2.38	15.81	249.90
51.	1951	618.92	-0.18	-2.55	-134.27	18028.88
52.	1952	582.40	-0.23	-2.78	-170.79	29169.78
53.	1953	586.50	-0.22	-3.00	166.69	27786.11
54.	1954	856.97	0.14	-2.86	103.78	10769.94
55.	1955	885.40	0.18	-2.69	132.21	17479.05
56.	1956	1223.00	0.62	-2.06	469.81	220719.89
57.	1957	667.70	-0.11	-2.18	-85.49	7308.82
58.	1958	1124.70	0.49	-1.68	371.51	138018.42
59.	1959	664.90	-0.12	-1.80	-88.29	7795.41
60.	1960	1227.70	0.63	-1.17	474.51	225158.13
61.	1961	1089.70	0.45	-0.73	336.51	113237.84
62.	1962	659.80	-0.12	-0.85	-93.39	8722.00
63.	1963	949.80	0.26	-0.59	196.61	38654.84
64.	1964	942.60	0.25	-0.34	189.41	35875.51
65.	1965	821.60	0.09	-0.25	68.41	4679.70
66.	1966	489.30	-0.35	-0.60	-263.89	69638.81
67.	1967	976.70	0.30	-0.30	223.51	49955.99
68.	1968	709.80	-0.06	-0.36	-43.39	1882.84
69.	1969	852.70	0.13	-0.23	99.51	9901.91
70.	1970	760.00	0.01	-0.22	6.81	46.35
71.	1971	1153.27	0.53	0.32	400.08	160062.70
72.	1972	720.34	-0.04	0.27	-32.85	1079.23
73.	1973	704.21	-0.07	0.21	-48.98	2399.20
74.	1974	61.00	-0.19	0.02	-143.19	20503.85
75.	1975	1094.00	0.45	0.47	340.81	116150.33

1	2	3	4	5	6	7
76.	1976	790.00	0.05	0.52	36.81	1354.85
77.	1977	964.50	0.28	0.80	211.31	44651.22
78.	1978	797.00	0.06	0.86	43.81	1919.17
79.	1979	684.10	-0.09	0.76	-69.09	4773.66
80.	1980	966.40	0.28	1.05	213.21	45457.81
81.	1981	595.10	-0.21	0.84	-158.09	24992.98
82.	1982	781.60	0.04	0.88	28.41	807.03
83.	1983	1030.10	0.37	1.24	276.91	76678.22
84.	1984	406.30	-0.46	0.78	-346.89	120333.83
85.	1985	790.90	0.05	0.83	37.71	1421.92
86.	1986	526.30	-0.30	0.53	-226.89	51479.83
87.	1987	377.80	-0.50	0.03	-375.39	140918.91
88.	1988	870.40	0.16	0.19	117.21	13737.80
89.	1989	611.00	-0.19	0.00	-142.19	20218.46

DATA SOURCE : Regional Meteriological Centre, New Delhi.

APPENDIX - II

LITHOLOGICAL LOGS OF BOREHOLES DRILLED BY THE STATE TUBEWELL DEPARTMENT IN GANGA-KALI SUB BASIN

S.No.	LITHOLOGY	DEPTH	THICKNESS
LOCATION : MEERGARHI			
TUBEWELL No. 9			
1.	Surface clay	0 - 6.10	6.10
2.	Kankar	6.10 - 9.15	3.05
3.	Clay	9.15 -12.20	3.05
4.	Fine sand	12.20 -21.35	9.15
5.	Clay	21.35 -42.70	21.35
6.	Fine sand	42.70 -45.75	3.05
7.	Clay	45.75 -48.80	3.05
8.	Fine to medium sand	48.80 -51.85	3.05
9.	Medium sand	51.85 -73.20	21.35
10.	Medium to coarse sand	73.20 -87.00	13.8
11.	Light caving clay	87.00 -91.50	4.5
LOCATION : ATRAULI			
TUBEWELL No. 66			
1.	Surface clay	0 - 3.0	3.0
2.	Clay	3.00 - 6.00	3.00
3.	Lahal	6.00 -12.01	6.00
4.	Clay & Kankar	12.01 -15.01	3.00
5.	Fine to medium sand	15.01 -18.01	3.00

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
6.	Clay Kankar	18.01 - 48.64	30.63
7.	Fine sand	48.64 - 51.95	3.31
8.	Clay & Kankar	51.95 - 57.65	5.70
9.	Medium sand	57.65 - 66.06	8.41
10.	Medium to course sand	66.06 - 76.57	10.51
11.	Medium sand	76.57 - 80.48	3.91
12.	Clay Kankar	80.48 - 96.06	15.61

LOCATION : JAMONA

TUBEWEL No. 1

1.	Surface clay	0 - 3.00	3.00
2.	Clay Kankar	3.00 - 10.51	7.57
3.	Fine sand	10.51 - 19.51	9.00
4.	Clay Kankar	19.51 - 24.00	4.51
5.	Sand	24.00 - 33.00	9.00
6.	Clay Kankar	33.00 - 37.53	4.53
7.	Sand	37.53 - 40.54	3.00
8.	Clay	40.54 - 49.54	9.00
9.	Fine sand	49.54 - 52.55	3.00
10.	Clay Kankar	49.54 - 57.02	7.51
11.	Sand	57.05 - 69.06	12.00
12.	Clay Kankar	69.06 - 72.00	3.00

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
7.	Coarse sand with gravel	36.03 - 40.54	4.51
8.	Clay	40.54 - 48.04	7.50
9.	Sand, with Kankar	48.04 - 69.96	21.92
10.	Hard clay & Kankar	69.96 - 75.07	5.1
11.	Dirty fine sand	75.07 - 78.07	3.0
12.	Clay Kankar	78.07 - 90.09	12.02

LOCATION : GOBLI

TUBEWELL No. 171

1.	Surface clay	0 - 1.80	1.80
2.	Fine sand	1.80 - 8.10	6.30
3.	Sand with Kankar	8.10 - 9.30	1.20
4.	Sand fine	9.30 -18.91	9.61
5.	Clay & Kankar	18.91 -45.05	26.13
6.	Medium sand	45.05 -51.63	6.60
7.	Clay	51.65 -58.55	6.90
8.	Fine sand	58.55 -60.06	1.51
9.	Clay, clay Kankar, clay	60.06 -69.06	9.00
10.	Fine to medium sand	69.06 -74.06	10.51
11.	Clay	79.06 -93.09	14.03

LOCATION : GOBLI

TUBEWELL No. 172

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
1.	Surface clay	0 - 3.00	3.00
2.	Fine sand with clay	3.00 - 9.00	6.00
3.	Dand	9.00 -18.01	
4.	Clay	18.01 -24.00	
5.	Sand	24.00 -39.03	15.00
6.	Clay kankar	39.03 -44.44	5.4
7.	Fine to medium sand	51.95 -51.95	7.50
8.	Clay	51.95 -57.05	5.10
9.	Sand	57.05 -63.06	6.01
10.	Clay kankar	63.06 -72.07	9.00
11.	Sand	72.07 -82.28	10.21
12.	Clay	72.07 -90.09	18.02

LOCATION : KHERIA

TUBEWELL No. 173

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
1.	Surface clay	0 - 3.00	3.00
2.	Fine to medium sand	3.00 -15.00	12.00
3.	Sand clay	15.00 -18.00	3.00
4.	Clay & Kankar	18.00 -21.00	3.00
5.	Fine to medium sand	21.00 -34.53	13.53
6.	Clay & Kankar	34.53 -36.03	1.50

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : GHINAUNA			
TUBEWELL No. 108			
1.	Surface clay	0 - 3.00	3.00
2.	Sand	3.00 -72.00	69.00
3.	Clay & Kankar	72.00 -94.00	22.00
4.	Medium sand	94.00-124.00	30.00
5.	Clay Kankar	124.00-130.00	6.00
LOCATION : LOHGARH			
TUBEWELL No. 36			
1.	Surface clay	0 - 3.04	3.04
2.	Fine medium sand and sandstone	3.04 -20.70	17.60
3.	Brown clay	20.70 -33.50	12.80
4.	Fine medium sand brown clay	33.50 -35.06	1.50
5.	Brown clay	35.06 -50.30	15.20
6.	Fine medium sand grey	50.30 -57.90	7.60
7.	Medium sand	57.90 -64.02	6.12
8.	Medium sand	64.02 -67.07	3.10
9.	Course sand and gravel	67.07 -70.12	3.05
10.	Brown clay	70.12 -79.26	9.14
11.	Clay	79.26 -96.03	16.70

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
12.	Brown fine sand	96.03 - 97.50	1.5
13.	Medium sand	97.50 -109.70	12.20
14.	Brown fine sand	109.7 -112.20	1.50
15.	Clay	111.20 -113.70	2.50

LOCATION : SALARPUR

TUBEWELL No. 39

1.	Clay	0 - 6.70	6.70
2.	Fine sand	6.70 - 12.50	5.80
3.	Clay	12. 50 - 12.80	0.30
4.	Very coarse sand	12.80 - 21.30	8.50
5.	Coarse sand	21.30 - 22.80	1.50
6.	Clay and Kankar	22.80 - 51.80	28.90
7.	Fine sand	51.80 - 56.70	4.90
8.	Medium brown sand	56.70 - 59.14	2.40
9.	Fine sand	59.14 - 61.50	2.40
10.	Coarse sand	61.50 - 64.02	2.50
11.	Coarse sand and Kankar	64.02 - 65.80	1.8
12.	Bajri and sand	65.80 - 67.90	2.18
13.	Sand	67.90 - 73.40	5.50
14.	Clay	73.40 - 76.20	2.80

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : PIAOLI			
TUBEWELL No. 201			
1.	Surface clay	0.00 - 3.00	3.00
2.	Fine sand	3.00 - 30.00	27.00
3.	Clay and Kankar	30.00 - 40.00	10.00
4.	Fine to medium sand	40.00 - 50.00	10.00
5.	Medium sand and sandstone	50.00 - 78.00	28.00
6.	Hard clay	78.00 - 82.35	4.35
LOCATION : HARDOI			
TUBEWELL No. 241			
Surface clay		0.00 - 6.09	6.09
2.	Medium sand	6.09 - 21.34	15.25
3.	Sandy clay	21.34 - 30.48	9.14
4.	Fine to medium sand	30.48 - 48.78	18.30
5.	Medium sand	48.78 - 70.12	21.34
6.	Medium sand	70.12 - 73.15	3.03
7.	Sandy clay	73.15 - 76.20	3.06
8.	Medium sand	76.20 - 91.46	15.26
9.	Clay medium	91.46 -121.90	30.52

S.NO.	LITHOLOGY	DEPTH RANGE	THICKNESS

LOCATION : PITHANPUR

TUBEWELL No. 5

1.	Surface clay	0.00 - 3.04	3.04
2.	Fine sand	3.04 - 6.09	3.04
3.	Fine sand medium sand	6.09 - 27.70	21.60
4.	Clay with Kankar	27.70 - 30.40	2.70
5.	Fine sand with sandstone	30.40 - 39.00	8.60
6.	Clay with Kankar	39.00 - 50.30	11.30
7.	Fine sand with sandstone	50.30 - 54.80	4.50
8.	Fine to medium sand with sandstone	54.80 - 63.70	8.90
9.	Clay with Kankar	63.70 - 69.50	5.80
10.	Medium stone	69.50 - 82.30	12.80
11.	Medium sand with stone and pebbles	82.30 - 92.07	9.7
12.	Clay with Kankar	92.07 -100.6	7.9

LOCATION : PACHNALA

TUBEWELL No. 110

1.	Surface clay	0.00 - 3.05	3.05
2.	Fine sand	3.05 - 9.15	6.10
3.	Hard clay & Kankar	9.15 - 15.20	6.05
4.	Fine sand	15.20 - 18.30	3.10

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
5.	Hard clay	18.30 - 24.40	6.10
6.	Fine to Medium sand	24.40 - 33.55	9.15
7.	Clay Kankar	33.55 - 48.80	15.25
8.	Fine to medium sand	48.80 - 57.95	9.15
9.	Clay Kankar	57.95 - 79.80	21.85
10.	Medium sand	79.80 -109.00	29.20
11.	Clay with Kankar	109.00 -110.00	1.00

LOCATION : SIRAWALI

TUBEWELL No. 75

1.	Surface clay	0.00 - 4.60	4.60
2.	Fine sand	4.60 - 30.50	25.90
3.	Clay	30.50 - 50.00	19.50
4.	Sand	50.00 - 99.50	49.50
5.	Hard clay	99.50 -119.8	20.30

LOCATION : SIAPUR

TUBEWELL No. 56

1.	Surface clay	0.00 - 3.00	3.00
2.	Sand	3.00 - 21.02	18.02
3.	Hard clay	21.02 - 27.02	6.00
4.	Clay Kankar	27.02 - 30.03	3.01

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
5.	Sand	30.03 - 45.04	15.01
6.	Medium sand & Stone	45.04 - 57.05	12.01
7.	Sand with Kankar	57.05 - 63.66	6.61
8.	Clay & Kankar	63.66 - 69.06	5.40

LOCATION : NAMENI

TUBEWELL No. 89

1.	Surface clay	0.00 - 3.05	3.05
2.	Fine sand	3.05 - 18.30	15.25
3.	Clay and Kankar	18.30 - 24.40	6.10
4.	Medium sand	24.40 -127.10	102.70

LOCATION : BEGPUR

TUBEWELL No. 191

1.	Fine sand	0.00 - 9.51	9.51
2.	Clay Kankar	9.51 - 17.00	7.49
3.	Fine to Medium sand	17.00 - 24.40	7.40
4.	Clay with Kankar	24.40 - 27.30	2.90
5.	Sand	27.30 - 58.30	31.00
6.	Clay Kankar	58.30 - 66.00	7.70
7.	Sand	66.00 - 84.20	18.20
8.	Clay	84.20 - 91.50	7.20

LOCATION : ALAMPUR RAINI

TUBEWELL No. 117

S.No.	LITHOLOGY	THICKNESS	DEPTH RANGE
1.	Surface clay	0.00 - 3.96	3.96
2.	Fine sand	3.96 - 7.92	3.96
3.	Hard clay	7.92 - 11.88	3.96
4.	Fine sand	11.88 - 21.88	10.00
5.	Clay	21.88 - 26.88	5.00
6.	Kankar	26.88 - 30.21	3.33
7.	Fine sand	30.21 - 36.48	6.27
8.	Clay	36.48 - 48.36	11.88
9.	Sand	48.36 - 68.59	20.23
10.	Hard clay	68.59 - 73.85	5.26
11.	Sand	73.85 - 81.73	7.88

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS

LOCATION : DADON

TUBEWELL No. 222

1.	Surface clay	0.00 - 4.00	4.00
2.	Sand and clay	4.00 - 16.00	12.00
3.	Medium sand	16.00 - 21.00	9.00
4.	Clay and Kankar	21.00 - 28.00	7.00
5.	Yellow fine sand	28.00 - 36.00	8.00
6.	Clay and Kankar	36.00 - 52.00	16.00
7.	Medium sand	52.00 - 60.00	8.00
8.	Clay and Kankar	60.00 - 64.00	4.00
9.	Fine sand	64.00 - 68.00	4.00
10.	Medium sand	68.00 - 76.00	8.00
11.	Caving clay	76.00 - 98.00	22.00
12.	Fine to Medium sand	98.00 -100.00	2.00
13.	Medium sand	100.00 -112.00	12.00
14.	Caving clay	112.00 -120.00	8.00

LOCATION : PALI

TUBEWELL No. 57

1.	Surface clay	0.00 - 3.00	3.00
2.	Sandy clay	3.00 - 12.10	9.10
3.	Fine sand	12.10 - 36.50	27.40
4.	Medium sand with stone	36.50 - 40.20	3.70

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
5.	Kankar and clay	40.20 - 50.90	10.70
6.	Fine to Medium sand with stone	50.90 - 55.40	4.50
7.	Clay and Kankar	55.40 - 88.40	33.00
8.	Caving clay	88.40 - 93.90	5.50
9.	Medium sand	93.90 -113.70	19.80
10.	Clay and Kankar	113.70 -120.10	6.40
11.	Medium sand with stone	120.10 -127.40	7.30
12.	Clay kankar	127.40 -139.00	11.6

LOCATION : RUNPAN

TUBEWELL No. 56

1.	Surface clay	0.00 - 6.09	6.09
2.	Clay	6.09 - 12.19	6.12
3.	Sandy clay	12.19 - 24.30	12.20
4.	Fine sand	24.30 - 57.90	33.60
5.	Medium sand	57.90 - 79.20	21.30
6.	Kankar	79.20 - 82.30	3.10
7.	Clay	82.30 -103.60	21.30
8.	Medium sand	103.60 -121.90	18.30
9.	Fine sand	121.90 -128.00	6.10
10.	Sandy clay	128.00 -140.20	12.24

LOCATION : BADAUL

TUBEWELL No. 52

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
1.	Surface filling clay	0.03 - 3.04	3.04
2.	Fine sand yellow	3.04 - 6.08	3.04
3.	Fine sand and sandstone	6.08 - 15.20	9.12
4.	Clay and stone	15.20 - 24.32	9.12
5.	Fine sand	24.36 - 26.37	3.04
6.	Fine sand and sandstone	27.36 - 30.40	3.04
7.	Fine sand and sandstone bajri	30.40 - 33.44	3.04
8.	Clay and Kankar	33.44 - 36.48	3.04
9.	Fine sand, Bajri and sandstone	36.48 - 45.50	9.12
10.	Sandstone	45.60 - 48.64	3.04
11.	Clay and Kankar	48.64 - 51.68	3.04
12.	Fine sand, sandstone, Bajri and Pebbles	51.68 - 54.72	3.04
13.	Sandy clay and Kankar	54.72 - 57.76	3.04
14.	Fine sand to medium sand sandstone, Bajri and Kankar	57.76 - 69.92	12.16
15.	Hard clay	69.92 - 72.96	3.40

S.No.	LOCATION	DEPTH RANGE	THICKNESS

LOCATION : HABIBPUR

TUBEWELL No. 78

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay	3.04 - 15.20	12.20
3.	Fine sand	15.20 - 20.10	4.90
4.	Clay and Kankar	20.10 - 24.30	4.20
5.	Fine sand	24.30 - 28.90	4.60
6.	Hard clay	28.90 - 33.50	4.60
7.	Clay and Kankar	33.50 - 36.50	3.00
8.	Kankar	36.50 - 42.60	6.10
9.	Clay	42.60 - 48.70	6.10
10.	Fine sand	48.70 - 57.90	9.20
11.	Fine to medium sand and Kankar	57.90 - 65.60	7.90
12.	Clay and Kankar	65.60 - 77.40	11.80
13.	Kankar	77.40 - 79.20	1.90
14.	Very fine sand	79.20 - 82.30	3.10
15.	Clay and Kankar	82.30 - 96.00	13.70
16.	Fine to medium sand	96.00 -103.60	7.60
17.	Fine to medium sand with sandstone	103.60 -109.70	6.15
18.	Clay	109.70 -114.30	4.60

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : NAGLA KHANJI			
TUBEWELL No. 79			
1.	Surface clay	0.00 - 3.05	3.05
2.	Sand	3.05 - 48.80	45.75
3.	Medium sand with stone	48.80 - 54.90	6.10
4.	Sand	54.90 - 61.00	6.10
5.	Sand with stone	61.00 - 73.20	12.20
6.	Clay with Kankar	73.20 - 79.30	6.10
7.	Fine to medium sand	79.30 - 91.50	12.20
8.	Medium sand with stone	91.50 -123.00	31.50
LOCATION : KASGANJ			
TUBEWELL No. JAL NIGAM			
1.	Surface clay	0.00 - 0.90	0.90
2.	Sandy clay	0.90 - 4.50	3.60
3.	Fine sand and Kankar	4.50 - 21.62	17.12
4.	Fine to medium sand	21.60 - 44.10	22.52
5.	Clay and Kankar	44.10 - 57.05	12.95
6.	Fine to medium sand and Kankar	57.57 - 70.57	13.00
7.	Clay and Kankar	70.57 - 73.57	3.00
8.	Fine to medium sand	73.57 - 82.58	9.01
9.	Clay Kankar	82.58 - 93.09	10.51

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : SALEMPUR			
TUBEWELL No. 65			
1.	Surface clay	0.00 - 4.00	4.00
2.	Sand	4.00 - 52.00	48.00
3.	Clay	52.00 - 62.00	10.00
4.	Sand	62.00 - 99.00	37.00
5.	Clay and Kankar	99.00 -106.75	7.75
LOCATION : FIROZPUR			
TUBEWELL No. 103			
1.	Surface clay	0.00 - 3.00	3.00
2.	Fine sand	3.00 - 36.00	33.00
3.	Clay and Kankar	36.00 - 58.00	22.00
4.	Fine to medium sand	58.00 -113.00	58.00
5.	Clay and Kankar	113.00 -123.00	10.00
LOCATION : GANGIRI			
TUBEWELL No. 108			
1.	Surface clay	0.00 - 3.00	3.00
2.	Fine sand	3.00 - 6.00	3.00
3.	Clay and Kankar	6.00 - 12.01	6.01

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
4.	Fine to medium sand	12.01 - 30.94	18.92
5.	Clay	30.93 - 33.93	3.00
6.	Clay and Kankar	33.93 - 47.44	13.51
7.	Sand	47.44 - 52.25	4.81
8.	Clay and Kankar	52.25 - 66.06	13.81
9.	Sand	66.06 - 96.06	30.03
10.	Clay and Kankar	96.06 - 99.09	3.03

LOCATION : RUKHALA

TUBEWELL No. 102

1.	Surface clay	0.00 - 3.00	3.00
2.	Clay kankar	3.00 - 6.00	3.00
3.	Sand	6.00 - 24.02	18.00
4.	Clay kankar	24.02 - 30.00	6.00
5.	Sand	30.00 - 33.03	3.00
6.	Clay kankar	33.03 - 46.84	13.81
7.	Sand	46.84 - 56.75	9.91
8.	Clay kankar	56.75 - 75.07	18.32
9.	Sand	75.07 -102.70	27.63
10.	Clay kankar	102.70 -114.11	11.41

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : PUSAWALI			
TUBEWELL No. 96			
1.	Sticky clay	0.00 - 8.50	8.50
2.	Clay and kankar	8.50 - 13.40	4.90
3.	Medium sand	13.40 - 19.80	6.40
4.	Clay	19.80 - 29.20	9.40
5.	Clay and kankar	29.20 - 32.00	2.80
6.	Clay kankar	32.00 - 42.60	10.60
7.	Clay	42.60 - 50.30	7.70
8.	Sticky clay	50.30 - 57.90	7.60
9.	Clay stone	57.90 - 67.10	9.20
10.	Clay	67.10 - 72.50	5.40
11.	Medium sand	72.50 - 82.30	9.80
12.	Coarse sand	82.30 - 86.20	3.90
13.	Clay	86.20 - 90.20	4.00
14.	Fine to medium sand	90.20 - 97.50	7.30
15.	Fine sand	97.50 -100.00	2.50
16.	Fine medium sand	100.00 -103.60	3.60
17.	Kankar and sand stone	103.60 -105.70	2.10
18.	Clay	105.70 -109.70	4.00

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : UTRA			
TUBEWELL No. 183			
1.	Surface clay	0.00 - 3.00	3.00
2.	Clay and kankar	3.00 - 12.61	9.61
3.	Fine to medium sand	12.61 - 17.11	4.50
4.	Clay and kankar	17.11 - 27.02	9.91
5.	Hard clay	27.02 - 56.45	29.43
6.	Fine to medium sand	56.45 - 63.06	6.61
7.	Medium to coarse sand	63.06 - 67.56	4.50
8.	Medium to coarse sand	67.56 - 81.08	13.52
9.	Hard clay	81.08 - 90.00	8.92
1.	Clay	0.00 - 4.27	4.27
2.	Sand	4.27 - 5.49	1.22
3.	Clay	5.49 - 10.37	4.88
4.	Sand	10.37 - 18.60	8.23
5.	Clay	78.60 - 23.79	5.19
6.	Sand	23.79 - 29.89	6.10
7.	Clay	29.89 - 38.12	8.23
8.	Sand	38.12 - 45.45	7.33
9.	Clay	45.45 - 57.95	12.55
10.	Sand	57.95 - 61.00	3.05

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
11.	Clay	61.00 - 89.97	28.97
12.	Sand	89.97 -102.50	12.53
13.	Clay	102.50 -123.20	20.70
14.	Sand	123.20 -129.32	6.12
15.	Clay	129.32 -133.59	
16.	Medium sand	133.59 -135.40	1.81
17.	Clay	135.40 -139.08	

LOCATION : TIKTA

TUBEWELL No. 152

1.	Clay kankar	0.00 - 3.66	3.66
2.	Sand	3.66 - 19.52	15.86
3.	Clay	19.52 - 24.40	4.88
4.	Sand	24.40 - 27.14	2.74
5.	Clay	27.14 - 28.06	0.92
6.	Sand	28.06 - 29.28	1.22
7.	Clay	29.28 - 35.99	6.71
8.	Sand	35.99 - 38.43	2.44
9.	Clay	38.43 - 45.75	7.32
10.	Clay	45.75 - 53.98	8.23
11.	Sand	53.98 - 67.10	13.12
12.	Clay	67.10 - 69.23	2.13
13.	Sand	69.23 - 75.03	1.00
14.	Sand	75.03 - 83.57	8.57
15.	Clay	83.57 - 86.01	8.57

S.No.	LITHOLOGY	DEPTH RANGE	THICKNESS
LOCATION : CHANDAULI			
TUBEWELL No. 122			
1.	Surface clay	0.00 - 3.60	3.60
2.	Fine sand	3.60 - 6.00	2.40
3.	Fine to medium sand with stone	6.00 - 21.00	15.02
4.	Medium sand with kankar	21.00 - 33.03	12.03
5.	Hard clay	33.03 - 44.44	11.41
6.	Fine to medium sand	44.44 - 51.05	6.61
7.	Clay	51.05 - 57.65	6.60
8.	Clay and kankar	57.65 - 64.56	6.91
9.	Sand	64.56 - 82.88	5.44
10.	Hard clay	82.88 - 86.48	3.60

APPENDIX - III (A)

Results of mechanical analysis of aquifer material.

LOCATION : KHERIA

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.21	0.21	0.21	99.79
35	0.50	0.19	0.19	0.40	99.60
45	0.35	0.52	0.52	0.92	99.08
60	0.25	3.15	3.18	4.10	95.90
80	0.17	4.51	4.55	8.65	91.35
120	0.12	37.19	37.55	46.2	53.80
170	0.08	29.77	30.05	76.25	23.75
230	0.62	18.32	18.49	94.74	5.26
Pan	0.62	5.03	5.07	99.81	0.19

LOCATION : RUNPAN

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	2.68	2.69	2.69	97.31
35	0.50	0.18	0.18	2.87	97.13
45	0.35	0.29	0.29	3.16	96.84
60	0.25	3.05	3.06	6.22	93.78
80	0.17	6.12	6.15	12.37	87.63
120	0.12	41.96	42.22	54.59	45.41
170	0.08	24.39	24.54	79.13	20.87
230	0.06	15.15	15.24	94.37	5.63
Pan	0.06	5.55	5.85	100.24	0.00

LOCATION : CHAUMUHA

DEPTH 50'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	3.13	1.58	1.58	98.42
35	0.50	1.47	0.74	2.32	97.68
45	0.35	7.55	3.81	6.13	93.87
60	0.25	112.08	56.60	62.73	37.27
80	0.17	25.76	13.01	75.74	24.26
120	0.12	39.88	20.14	95.88	4.12
170	0.08	4.52	2.28	98.16	1.84
230	0.06	2.39	1.20	99.36	0.64
Pan	0.06	1.21	0.61	99.97	0.00

LOCATION : GHAZIPUR

DEPTH 120'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	6.09	3.08	3.08	96.92
35	0.50	4.28	2.17	5.25	94.75
45	0.35	23.11	11.70	16.95	83.05
60	0.25	109.37	55.41	72.36	27.64
80	0.17	17.32	8.77	81.13	18.87
120	0.12	29.45	14.92	96.05	3.95
170	0.08	3.22	1.63	97.68	2.32
230	0.06	3.22	1.63	99.31	0.69
Pan	0.06	1.29	0.06	99.96	0.04

LOCATION : GHINAUNA

DEPTH 60'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.96	0.48	0.48	99.52
35	0.50	1.91	0.96	1.44	98.56
45	0.35	6.87	3.46	4.90	95.10
60	0.25	73.14	36.98	41.88	58.12
80	0.17	41.05	20.75	63.63	37.37
120	0.12	60.68	30.68	93.31	6.69
170	0.08	6.30	3.18	96.99	3.51
230	0.06	3.37	1.70	98.19	1.81
Pan	0.06	3.49	1.76	99.95	0.05

LOCATION : FIROZPUR SUHELA

DEPTH 26'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.19	0.09	0.09	99.91
35	0.50	0.22	0.11	0.20	99.98
45	0.35	1.88	0.95	1.15	98.85
60	0.25	43.39	21.89	23.04	76.96
80	0.17	37.92	19.13	42.17	57.83
120	0.12	91.32	46.09	99.25	11.57
170	0.08	15.59	7.87	96.12	3.88
230	0.06	5.77	2.91	99.03	0.97
Pan	0.06	1.83	0.92	99.95	0.00

LOCATION : DHOLANA

Mesh No.	Size in (mm)	Weight retained in gram	**Weight % retained**	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.80	0.08	0.80	99.92
35	0.50	0.48	0.48	0.56	99.44
45	0.35	2.50	2.53	3.09	96.91
60	0.25	31.65	32.14	35.23	64.77
80	0.17	23.53	23.89	59.12	40.88
120	0.12	32.93	33.44	92.56	7.44
170	0.08	4.15	4.21	96.77	3.29
230	0.06	1.62	1.64	98.41	1.59
Pan	0.06	0.81	0.82	99.23	0.77

APPENDIX - III (B)

Results of mechanical analysis of the Ganga sand.

LOCATION : GANGA - MOOHAMMADPUR

DEPTH : 30'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.02	0.02	0.02	99.98
35	0.50	0.10	0.10	0.12	99.88
45	0.35	0.69	0.70	0.82	99.18
60	0.25	13.09	13.30	14.12	85.88
80	0.17	23.14	23.51	37.63	62.37
120	0.12	51.64	52.46	90.09	9.91
170	0.08	7.42	7.53	97.62	2.38
230	0.06	1.87	1.90	99.52	0.48
Pan	0.06	0.44	0.44	99.96	0.04

LOCATION : GANGA - MOHAMMADPUR

DEPTH : 60 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.03	0.03	0.03	99.97
35	0.50	0.09	0.09	0.12	99.88
45	0.35	0.37	0.37	0.49	99.51
60	0.25	2.49	2.50	2.99	97.01
80	0.17	6.22	6.26	9.25	90.75
120	0.12	51.97	52.35	61.60	38.40
170	0.08	24.46	24.63	86.23	13.77
230	0.06	10.26	10.33	96.56	3.44
Pan	0.06	3.38	3.40	99.96	0.04

LOCATION : MAHMOODPUR

DEPTH : 1 m

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.03	0.03	0.03	99.97
35	0.50	0.06	0.06	0.09	99.91
45	0.35	0.26	0.26	0.35	99.65
60	0.25	2.68	2.71	3.06	96.94
80	0.17	7.42	7.50	10.56	89.44
120	0.12	58.67	59.34	69.90	30.10
170	0.08	21.37	21.61	91.51	8.49
230	0.06	6.60	6.60	98.10	1.89
Pan	0.06	1.77	1.79	99.90	0.00

LOCATION : GANGA (K)

DEPTH : 30 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.02	0.02	0.02	99.98
35	0.50	0.06	0.06	0.08	99.92
45	0.35	0.50	0.50	0.13	99.87
60	0.25	8.98	9.08	9.21	90.79
80	0.17	18.39	18.600	27.81	72.19
120	0.12	52.90	53.49	81.30	18.70
170	0.08	10.07	10.18	91.48	8.52
230	0.06	4.87	4.92	96.40	3.60
Pan	0.06	3.09	3.12	99.52	0.48

LOCATION : GANGA (K)

DEPTH : 60 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.02	0.02	0.02	99.98
35	0.50	0.97	0.09	0.11	99.89
45	0.35	0.51	0.51	0.62	99.38
60	9.25	3.49	3.54	0.41	95.84
80	0.17	7.23	7.34	11.5	88.50
120	0.12	53.11	53.87	65.37	34.63
170	0.08	20.10	20.40	85.77	14.23
230	0.06	11.12	11.30	97.07	2.93
Pan	0.06	2.86	2.90	99.97	0.00

LOCATION : GANGA (K)

DEPTH : 90 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.01	0.01	0.01	99.99
35	0.50	0.06	0.06	0.07	99.93
45	0.35	0.35	0.35	0.42	99.58
60	0.25	3.85	3.89	4.31	95.69
80	0.17	16.93	17.11	21.42	78.58
120	0.12	53.10	53.69	75.10	24.89
170	0.08	17.98	18.17	93.28	6.72
230	0.06	3.57	3.60	96.88	3.12
Pan	0.06	3.05	3.08	99.96	0.04

APPENDIX - III (C)

Results of mechanical analysis of Kali River sand.

LOCATION : KALI RIVER (RAILWAY BRIDGE)

DEPTH : 30 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	00.84	-	-	-	100.00
25	0.71	0.41	0.04	0.04	99.96
35	0.50	0.17	0.17	0.21	99.79
45	0.35	0.67	0.67	0.88	99.12
60	0.25	3.82	3.83	4.71	95.29
80	0.17	5.72	5.74	10.45	89.55
120	0.12	46.32	46.54	56.99	43.01
170	0.08	26.19	26.31	83.30	16.70
230	0.06	11.43	11.48	94.79	5.22
Pan	0.06	5.15	5.17	99.96	0.00

LOCATION : KALI RIVER (RAILWAY BRIDGE)

DEPTH : 60 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.45	0.45	0.45	99.55
35	0.50	0.92	0.93	1.38	98.62
45	0.35	2.28	2.31	3.69	96.31
60	0.25	6.54	6.64	10.33	89.67
80	0.17	6.00	6.09	16.42	83.58
120	0.12	44.71	45.42	61.84	38.16
170	0.08	20.38	20.70	82.54	17.46
230	0.06	11.02	11.19	93.73	6.27
Pan	0.06	6.11	6.20	99.93	0.00

LOCATION : KALI RIVER (RAILWAY BRIDGE)

DEPTH : 90 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.30	0.30	0.30	99.70
35	0.50	1.84	1.84	2.14	97.86
45	0.35	4.58	4.62	6.76	93.24
60	0.25	7.13	7.20	13.96	86.04
80	0.17	5.59	5.60	19.60	80.40
120	0.12	40.69	41.07	60.67	39.33
170	0.08	20.31	20.73	81.40	18.60
230	0.06	11.75	11.86	93.26	6.74
Pan	0.06	6.88	6.94	100.00	0.00

LOCATION : KALI RIVER (ROAD BRIDGE)

DEPTH : 30 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.04	0.04	0.04	99.96
35	0.51	0.16	0.17	0.21	99.79
45	0.35	0.55	0.56	0.77	99.23
60	0.25	4.22	4.26	5.03	94.97
80	0.17	7.68	7.75	12.78	87.22
120	0.12	57.82	58.38	71.16	28.84
170	0.08	19.42	19.61	90.77	9.23
230	0.06	6.69	6.75	97.52	2.48
Pan	0.06	2.19	2.21	99.73	0.00

LOCATION : KALI RIVER (ROAD BRIDGE)

DEPTH : 60 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.01	0.01	0.01	99.99
35	0.50	0.07	0.07	0.80	99.92
45	0.35	0.21	0.21	0.29	99.71
60	0.25	2.54	2.55	2.84	97.16
80	0.17	6.82	6.86	9.70	90.30
120	0.12	60.82	61.24	70.94	29.06
170	0.08	20.58	20.72	91.66	8.34
230	0.06	6.47	6.51	98.17	1.83
Pan	0.06	1.72	1.73	99.99	0.00

LOCATION : KALI RIVER (ROAD BRIDGE)

DEPTH : 90 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.01	0.01	0.01	99.90
35	0.50	0.09	0.09	0.11	99.58
45	0.35	0.32	0.32	0.53	93.14
60	0.25	6.34	6.44	6.97	74.25
80	0.17	18.58	18.89	25.86	16.57
120	0.12	56.72	57.68	93.54	5.44
170	0.08	10.95	11.13	94.67	1.94
230	0.06	3.44	3.50	98.17	1.94
Pan	0.06	1.87	1.90		0.00

APPENDIX - IV (A)

HYDROGEOLOGICAL DATA OF DUGWELLS INVENTORIED IN THE GANGA-KALI SUB-BASIN IN PARTS OF ALIGARH AND ETAH DISTRICT. (JUNE-1988 — NOVEMBER, 1988)

Sl. No.	Location	Dia Meter (M)	M.P. (AGL)	Depth of the well	R.L. of M.P.	Pre-monsoon				Post-monsoon				A water level fluctuation	Temp.
						Date	Depth of water B.M.	D.T.W. B.G.L.	W.L. a.m.S.L	Date	D.T.W. (B.M.)	D.T.W. (BGL)	W.L. a.m. S.L.		
1.	Atrauli	1.27	0.97	17.0	186	6.6.88	15.65	14.68	170.35	6.11.88	14.60	13.63	171.4	1.05	25°C
2.	Pilkhunj	1.40	0.55	16.15	186	"	15.60	15.05	170.4	"	14.25	13.70	171.75	1 35	
3.	Rajmargpur	1.30	0.51	15.0	188	"	14.72	14.2	173.28	"	14.25	13.75	173.75	0.45	
4.	Harcharandpur	1.20	0.52	11.0	186	"	9.40	8.9	176.6	"	10.55	10.05	175.45	1.15	
5.	Raipur	1.25	0.57	12.50	186	"	12.40	11.87	173.6	"	11.65	11.08	174.35	0.70	
6.	Jirauli	1.00	0.9	12.50	186	"	11.60	10.7	174.4	"	11.0	10.1	175.0	0.60	
7.	Gobindpur	1.20	0.70	9.67	185	"	9.40	8.7	175.6	"	8.6	7.9	176.4	0 8	
8.	Chakhathal	1.00	G.L.	6.90	185	"	6.30	6.30	178.7	"	5.70	5.70	179.3	0.60	
9.	Mohammadpur	1.20	0.7	8.4	183	"	7.75	7.05	175.25	"	6.55	5.85	176.45	1.2	
10.	Kheria Bhadurgarhhi	1.40	0.10	12.50	186	"	11.70	11.60	174.30	"	11.35	11.25	174.65	0.35	
11.	Bembirpur	1.00	G.L.	14.00	188	"	13.00	13.00	175.00	"	12.50	12.50	175.50	0.50	
12.	Qasimpur	2.25	0.70	14.70	185	7.6.88	14.30	13.60	170.7	"	14.50	13.8	170.5	0.20	25°C
13.	Badauli	1.85	1.5	14.40	186	"	14.20	12.7	171.8	7.11.88	14.0	12.5	172.0	0.2	
14.	Gadaipur	1.25	0.70	12.15	186	"	12.00	11.30	174.0	"	11.95	11.25	174.05	0.05	
15.	Basai	1.35	0.50	13.80	187	"	13.40	12.9	173.6	"	12.70	12.2	174.30	0.7	
16.	Alampur	1.00	0.45	12.60	187	"	11.75	11.30	175.25	3.11.88	11.10	10.65	175.9	0.65	
17.	Lohgarh	1.00	0.55	13.25	186	8.6.88	11.20	10.65	174.8	"	10.00	9.45	176.00	1.2	
18.	Salarpur	1.20	0.45	13.0	184	"	10.30	9.85	173.7	"	9.8	9.35	174.2	0.5	
19.	Mahera	1.20	0.65	12.20	184	"	10.35	9.7	173.65	"	9.95	9.3	174.0	0.4	
20.	Balipur	1.00	0.70	14.000	184	"	12.00	11.3	172	"	11.4	10.7	172.6	0.6	

1	2	3	4	5	6	7	8	9	10	111	12	13	14	15	16
21.	Pipri	1.00	0.65	13.5	182	8.6.88	10.37	9.72	171.7	3.11.88	9.57	8.92	172.4	0.8	25°C
22.	Lahaski	1.20	0.65	12.00	184		10.47	9.8	173.5	"	9.87	9.22	170.15	0.6	
23.	Gaonkhera	1.20	0.33	14.60	185	"	14.55	14.22	170.45	"	13.85	13.52	171.5	0.70	
24.	Muhsanpur	1.15	0.45	13.50	185	"	13.35	12.9	171.65	"	12.80	12.35	172.2	0.55	
25.	Maghuwan	1.95	0.50	12.20	183	"	11.60	11.1	171.4	"	10.9	10.40	172.1	0.70	
26.	Pali	1.50	0.45	12.5	185	"	12.8	12.35	172.65	"	11.65	11.2	173.35	0.70	
27.	Badesra	1.10	0.15	10.90	182	"	10.75	10.60	171.2	"	9.6	9.2	172.4	1.4	25°C
28.	Badaul	1.15	0.30	12.0	182	"	9.6	9.3	172.4	"	8.4	8.1	173.6	0.3	
29.	Bijauli	0.80	0.75	13.76	183	"	13.30	12.55	169.7	"	12.80	12.05	170.2	0.75	
30.	Sidh	1.05	0.20	12.00	182	"	10.75	10.55	171.25	"	9.65	9.45	172.35	1.1	
31.	Rumami	1.25	0.90	11.20	180	"	10.8	9.9	169.2	"	9.4	8.5	170.6	1.4	
32.	Pindol	0.55	0.50	8.9	180	"	8.6	8.1	171.4	"	7.2	6.7	172.8	1.4	
33.	Shaikhpur	0.8	0.1	8.00	180	"	7.8	7.7	172.2	4.11.88	6.3	6.2	173.2	1.5	
34.	Singhpur	1.2	0.2	12.00	182	9.6.89	10.60	10.40	171.4	"	9.90	9.7	172.1	0.70	
35.	Sirsa	1.2	0.40	11.30	182	"	10.1	9.7	172.0	"	9.3	8.9	172.7	0.60	
36.	Bhuria	1.0	0.4	13.5	183	"	11.6	11.2	171.8	"	10.7	10.3	172.3	0.5	
37.	Charra	1.5	G.L.	14.00	180	"	12.48	12.48	167.52	"	11.8	11.8	168.2	0.68	
38.	Narauna	1.10	0.43	12.80	182	"	12.00	11.57	170.0	"	11.40	10.97	170.6	0.6	
39.	Chaumuhan	1.64	0.45	11.50	183	"	11.30	10.85	171.7	"	11.00	10.55	172.00	0.3	
40.	Mirgarhi	1.20	0.30	12.00	182	"	11.40	11.10	170.6	"	10.9	10.6	171.1	0.50	
41.	Gobli	1.00	0.50	10.5	183	"	9.35	8.85	173.7	"	9.43	7.93	174.57	0.92	
42.	Ahmadpura	1.2	0.45	11.00	181	"	9.00	8.55	173.0	"	8.3	7.85	173.7	0.7	
43.	Chandauli Buzarg	1.20	G.L.	12.5	182	"	9.75	9.75	172.25	5.11.88	9.3	9.3	172.7	0.45	
44.	Surajpur	1.00	0.90	15.0	184	10.6.88	13.15	12.25	170.9	"	13.65	12.75	170.35	0.5	
45.	Ganiawal	1.15	0.80	14.6	186	"	12.84	13.04	171.6	"	13.65	12.85	172.35	0.81	
46.	Fazalpur	2.9	0.55	14.80	186	"	14.65	14.1	171.4	"	14.45	13.9	171.55	0.2	
47.	Alampur	1.7	0.33	15.2	184	"	13.2	12.9	170.8	"	12.65	12.32	171.35	0.58	
48.	Chauchai	1.20	0.20	13.4	182	"	11.95	11.75	170.05	"	10.80	10.60	171.20	1.15	
49.	Gazipur	1.30	0.60	13.47	184	"	13.10	12.50	170.9	"	12.70	12.10	171.30	0.4	
50.	Madapur	0.97	0.80	14.10	184	"	13.95	13.15	170.05	"	13.50	12.70	170.50	0.45	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
51.	Piploi	1.30	0.50	14.1	183	10.6.88	13.95	13.45	169.05	5.11.88	13.5	13.0	169.51	0.45	
52.	Utra	1.60	0.40	13.30	183	'	12.95	12.55	170.05	"	12.40	12.00	170.60	0.55	
53.	Barla	2.80	0.85	17.32	184	"	15.90	15.05	168.10	"	14.65	13.80	169.35	1.25	
54.	Arani	1.70	0.80	13.00	181	"	11.00	10.20	170.00	""	10.40	9.60	170.60	0.60	
55.	Detaoli	1.10	0.25	14.70	181	"	14.60	14.35	166.40	"	13.70	13.45	167.30	0.90	
56.	Chandgarhi	0.80	G.L.	11.50	179	"	11.15	11.15	167.85	"	10.20	10.20	168.80	0.95	
57.	Nosha	0.80	0.30	16.70	184	"	16.50	16.20	167.50	"	15.30	15.00	168.70	1.20	
58.	Sunhera	1.20	0.70	14.40	182	"	13.70	13.00	168.30	"	12.60	11.90	169.40	1.1	
59.	Dhansari	1.00	0.50	12.40	179	"	12.30	11.80	166.70	"	11.80	11.30	167.20	0.50	
60.	Rukhela	0.86	1.00	10.80	179	12.6.88	10.10	9.10	168.10	6.11.88	9.60	8.60	169.40	0.50	
61.	Gangiri	0.96	0.40	13.45	178	"	13.30	12.90	164.70	"	11.40	11.00	166.40	1.90	
62.	Dhanisinghpur	1.25	0.45	10.90	178	"	10.35	9.90	167.65	"	9.60	9.15	168.40	0.75	
63.	Hidramai	1.00	0.10	11.30	178	"	11.10	11.00	166.90	"	9.90	9.80	168.10	1.20	
64.	Mahula	1.25	1.10	12.80	179	"	11.90	10.80	167.10	"	10.90	9.80	168.10	1.00	
65.	Malsi	0.90	0.60	10.80	177	"	10.00	9.40	167.00	"	8.40	7.80	168.60	1.60	
66.	Bilona	1.25	0.55	9.15	176	"	8.50	7.95	167.50	"	6.50	5.95	169.50	2.00	
67.	Naugaon	1.20	0.80	8.70	180	"	8.50	7.70	171.50	"	7.20	6.40	172.80	1.30	
68.	Tandoli	1.50	0.60	8.25	178	"	7.80	7.20	170.20	"	7.10	6.50	170.90	0.70	
69.	Jareth	1.00	0.45	5.40	177	"	4.90	4.45	172.10	"	3.20	2.75	173.80	1.70	
70.	Rajmau	1.20	0.50	5.15	177	"	3.46	2.96	173.50	"	1.81	1.31	175.20	1.65	
71.	Maopura	1.20	0.60	8.00	180	"	7.20	6.60	178.80	"	5.60	5.00	174.40	1.60	
72.	Bhikhampur	1.50	0.90	12.00	180	"	9.25	8.30	170.80	"	7.50	6.60	172.50	1.70	
73.	Nagla Talia	0.75	0.30	7.50	180	"	4.70	4.40	175.30	"	3.15	2.85	176.85	1.55	
74.	Nagla Dheemer	1.50	0.30	6.00	179	"	4.40	4.10	174.60	"	2.80	2.50	176.20	1.60	
75.	Bhamori Buzurg	1.00	0.50	9.45	180	"	8.35	7.85	171.65	"	7.55	7.05	172.45	0.80	
76.	Ata	1.10	0.20	8.00	180	13.6.88	5.90	5.70	174.10	7.11.88	6.30	5.00	173.70	0.70	
77.	Dadon	1.10	0.50	7.00	180	"	5.60	5.10	174.40	"	4.20	4.00	175.80	1.60	
78.	Bhurka Nagla	1.00	0.20	8.00	181	"	6.00	5.80	175.00	"	4.50	4.30	176.50	1.50	
79.	Alampur	1.20	0.40	7.50	180	"	4.25	3.85	175.80	"	3.40	3.00	176.60	0.85	
80.	Sarak ka Nagla	1.20	0.40	8.50	182	"	7.00	6.60	175.00	"	6.00	5.60	176.00	1.00	
81.	Shamsh Pur	0.75	0.25	8.5	184	"	7.00	6.75	177.00	"	6.20	5.95	177.80	0.8	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
82.	Sankra	1.25	0.40	8.0	177	13.6.88	5.70	5.30	171.30	7.11.88	4.90	4.50	172.10	0.80	23°C
83.	Dinapur	0.95	0.35	4.5	175	"	2.2	1.86	172.20	"	1.50	1.15	173.50	0.70	
84.	Todarpur	0.95	0.35	5.0	176	"	2.70	2.35	173.30	"	1.70	1.35	174.50	1.00	
85.	Gangbas	1.00	0.40	6.5	176	"	2.50	2.10	173.50	"	1.65	1.25	174.35	0.85	
86.	Gopalpur	1.20	0.50	4.00	171	"	2.80	2.30	168.20	"	1.80	1.30	160.20	1.00	
87.	Kanchanpur	1.00	0.45	5.00	172	"	2.70	2.25	169.30	"	2.00	1.55	170.00	0.70	
88.	Mokhampur	1.00	0.35	6.50	180	"	3.10	2.75	177.00	"	2.30	1.95	177.70	0.80	
89.	Pithanpur	1.25	0.65	9.50	184	"	7.20	6.55	176.80	"	6.35	5.70	177.60	0.85	
90.	Piauli	1.20	0.35	6.00	181	14.6.88	4.10	3.75	176.90	8.11.88	3.25	2.90	177.70	0.85	
91.	Narupura	1.00	0.50	9.00	182	"	7.50	7.00	174.50	"	6.80	6.30	175.20	0.70	
92.	Bhojpur	0.90	0.60	6.00	180	"	5.10	4.50	174.90	"	4.45	3.85	175.55	0.65	
93.	Hardoi	1.00	0.80	8.00	184	"	6.80	6.00	177.20	"	5.40	4.60	178.60	1.40	
94.	Dattacholi Buzurg	0.90	0.20	10.00	181	"	7.40	7.20	173.60	"	6.10	5.90	174.90	1.30	
95.	Bahona Katra	1.00	0.45	8.50	180	"	5.10	4.65	175.35	"	4.40	3.95	175.60	0.70	
96.	Khandawa	1.00	0.35	6.00	180	"	3.65	3.30	176.35	"	2.50	2.15	177.50	1.15	
97.	Ismailpur	1.00	0.70	4.00	171	"	2.90	2.20	168.10	7.11.88	1.70	1.00	169.30	1.20	
98.	Kotra	1.30	3.50	6.10	173	16.6.88	2.30	1.95	170.70	10.11.88	1.60	1.25	171.40	0.70	
99.	Jakhardarapur	1.20	0.60	9.50	175	"	8.50	7.90	166.50	"	7.40	6.80	167.60	1.10	
100.	Mamon	1.50	0.40	8.00	171	"	7.46	7.06	163.54	"	6.50	6.10	164.50	0.96	
101.	Gorha	1.80	0.75	7.70	171	"	7.20	6.45	163.80	"	6.20	5.45	164.80	1.00	
102.	Narauli	1.00	0.80	7.60	171	"	5.78	4.98	165.22	"	3.90	3.10	167.10	1.88	
103.	Kisrauli	1.60	0.50	7.10	174	"	5.20	4.70	168.80	"	3.50	3.00	170.50	1.70	
104.	Maharajpur	2.00	0.30	6.70	175	"	5.10	4.80	169.90	"	3.60	3.30	171.40	1.50	25°C
105.	Barwari Klan	1.70	0.45	6.70	175	"	4.67	4.22	170.33	"	3.50	3.05	171.50	1.17	
106.	Kasganj	1.50	1.00	14.40	172	"	10.25	9.25	161.25	"	8.75	7.75	163.30	0.50	
107.	Namaini	1.10	1.40	8.00	177	"	6.90	5.50	170.10	11.11.88	5.40	4.00	171.60	1.50	
108.	Kindi	1.80	0.20	7.10	176	"	6.30	6.10	169.70	"	4.60	4.40	171.40	1.70	
109.	Kumrawwa	1.50	0.80	8.80	182	"	7.33	6.50	174.70	"	6.65	5.85	175.30	0.65	
110.	Pachlana	1.15	0.50	6.20	176	"	5.90	5.45	170.10	"	5.20	4.70	170.80	0.75	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
111.	Sirauli	1.65	0.60	9.20	172	17.6.88	8.80	8.20	163.20	11.11.88	7.30	6.70	164.70	1.50	25°C
112.	Chandaus	1.20	0.40	7.00	172	"	5.10	4.70	167.00	"	3.75	3.35	168.30	1.35	
113.	Siapur	1.10	0.45	5.50	170	"	5.00	4.55	165.00	"	3.10	2.65	166.90	1.90	
114.	Saleempur	1.30	0.23	4.50	170	"	4.20	4.00	165.80	"	2.90	2.70	167.10	1.30	
115.	Bhaupur	1.20	0.65	6.00	170	"	4.60	3.95	165.40	"	3.10	2.45	166.60	1.50	
116.	Fatehpurkalan	1.10	0.65	5.00	169	"	4.55	3.90	164.50	"	2.65	1.95	166.35	1.95	
117.	Soron	1.30	0.60	10.0	172	"	0.9	8.4	163.6	"	0.8	7.4	164.00	1.00	
118.	Kadarbari	1.20	0.50	5.00	175	"	4.50	4.00	170.50	"	2.70	2.20	172.3	1.80	
119.	Jaretha	1.00	0.30	5.00	167	"	4.50	4.20	162.80	"	2.70	2.40	164.30	1.80	
120.	Banupur	1.20	0.70	5.00	166	"	4.20	3.50	161.80	12.11.88	3.10	2.40	162.90	1.10	
121.	Baraudha	1.00	0.60	5.00	168	"	4.60	4.00	163.40	"	2.85	2.25	165.15	1.45	
122.	Alipur	1.20	0.50	5.00	168	"	3.50	3.00	164.5	"	2.20	1.80	165.8	1.20	
123.	Tolakpur	1.50	0.70	5.00	168	"	4.50	3.80	163.50	"	2.85	2.15	165.10	1.65	
124.	Hodalpur	1.00	0.70	5.90	168	"	4.85	4.15	169.85	"	3.85	3.15	170.85	1.00	
125.	Deoriprahladpur	1.00	G.L	4.80	170	"	4.80	4.80	163.15	"	3.85	3.85	166.15	1.00	
126.	Nagla Khanji	1.30	0.73	7.90	175	"	7.10	6.37	168.63	"	**6.00**	**5.27**	**169.73**	**1.00**	
127.	Khairpur	1.20	1.00	10.00	179	"	9.70	8.70	169.30	"	8.25	7.25	170.75	1.45	
128.	Nagla Bari	1.30	0.70	6.00	170	"	3.90	3.20	166.10	"	2.85	2.15	167.15	1.05	
129.	Barkula	1.20	0.60	7.50	170	"	4.20	3.6	165.8	"	2.70	2.10	167.90	1.50	
130.	Zauddinpur	1.00	0.50	7.40	171	"	5.60	5.10	165.40	13.11.88	4.34	3.84	166.66	1.26	23°C
131.	Dhantauria	1.20	0.50	9.60	171	"	7.22	6.72	163.80	"	6.10	5.60	164.90	1.27	
132.	Faridpur	1.80	0.23	8.00	174	"	7.10	6.87	166.10	"	5.90	5.67	168.10	1.20	
133.	Danialganj	0.90	0.50	5.80	172	"	4.90	4.40	167.10	"	4.40	3.90	167.60	0.50	
134.	Nagla Bidhari	2.50	0.50	6.00	170	"	4.20	3.70	165.80	"	3.90	3.40	166.10	0.30	
135.	Jakhera	1.00	0.55	9.30	173	"	9.20	8.65	163.80	"	8.70	8.15	164.30	0.50	
136.	Saleempur	1.00	0.50	10.60	175	"	10.00	9.50	165.00	"	8.60	8.10	166.40	1.20	
137.	Satpura	1.00	0.30	9.60	176	"	9.50	9.20	166.50	"	8.60	8.30	167.40	0.90	
138.	Bilram	1.30	0.80	13.00	177	"	9.95	9.15	167.00	"	7.90	7.10	169.10	2.05	
139.	Rahmetpur	1.20	0.60	8.40	177	"	7.90	7.30	169.10	"	6.70	6.10	170.30	1.20	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
140.	Naugawan	1.10	0.45	6.00	177	18.6.88	5.00	4.55	172.00	13.11.88	4.00	3.50	173.00	1.00	25°C
141.	Barhera	1.80	0.50	11.00	176	"	10.00	9.50	166.00	"	8.73	8.30	167.27	1.27	
142.	Firozpur	1.30	0.60	10.50	176	"	9.95	9.35	166.05	"	8.70	8.10	167.30	1.25	
143.	Firozpur Suhela	1.40	G.L.	7.80	175	"	7.40	7.40	167.40	"	6.10	6.10	168.10	1.30	
144.	Karsari	1.15	0.65	11.50	176	"	9.20	8.55	166.80	"	7.90	7.25	168.10	1.30	
145.	Dholna	1.70	0.25	9.80	176	"	8.60	8.35	167.40	"	7.50	7.25	168.50	1.10	
146.	Wahidpur Mafi	2.10	0.45	9.50	177	"	8.50	8.05	168.50	"	7.40	6.95	169.60	1.10	
147.	Kanawa	1.20	0.30	7.00	174	18.6.88	6.30	6.00	167.70	"	4.63	4.33	169.37	1.67	
148.	Chhora	1.30	0.60	7.00	177	"	4.70	4.10	172.30	"	3.00	2.40	174.00	1.70	
149.	Ikhauna	1.20	0.30	6.10	177	"	5.30	5.30	171.70	"	3.00	2.70	174.00	1.70	
150.	Ghinauna	1.20	0.50	5.30	175	"	5.00	4.50	170.00	"	3.70	3.20	171.30	1.30	
151.	Garhi H.	1.00	0.80	5.00	174	"	4.35	3.55	169.50	"	2.20	1.40	171.80	2.15	
152.	Akbarpur	2.20	0.70	5.00	175	"	4.80	4.10	170.90	"	3.10	2.40	171.90	1.70	
152.	Nagla Ambar	2.40	0.70	4.30	176	"	4.10	3.40	172.00	"	2.10	1.40	173.90	2.00	
153.	Tabalpur	1.00	0.50	8.00	174	"	6.00	5.50	168.00	"	4.00	3.50	170.00	1.50	
154.	Nagla Dhak	1.30	0.40	6.00	177	"	4.60	4.20	172.40	"	2.90	1.00	174.10	1.70	
155.	Kaser	1.00	0.50	6.50	177	"	5.00	4.50	172.50	"	3.45	2.95	173.55	1.55	
156.	Ajwanthar	1.00	0.50	4.00	180	"	3.00	2.50	177.50	14.11.88	2.20	1.70	277.80	0.80	
157.	Begpurr	1.20	0.40	5.50	180	"	2.70	2.40	177.00	"	1.90	1.50	178.10	0.90	
158.	Nagla Moti	1.00	0.35	6.00	178	"	4.60	3.25	173.40	"	3.00	2.65	175.00	1.60	
159.	Kudhar	1.30	0.40	5.60	178	"	4.90	4.50	173.10	"	3.10	2.70	174.90	1.80	

APPENDIX - IV (B)

HYDROGEOLOGICAL DATA OF DUGWELLS INVENTORIED IN KALI-GANGA SUB-BASIN IN PARTS OF ALIGARH ETAH DISTRICTS (JUNE 1989 - NOVEMBER 1989).

Sl. No.	Location	Diameter (M)	M.P. (AGL)	Depth of the well	R.L. of M.P.	Pre-monsoon				Post-monsoon				A water level fluctuation	Temp.
						Date	Depth of water B.M.	D.T.W. B.G.L.	W.L. a.m. S.L.	Date	D.T.W. (B.M.)	D.T.W. (BGL)	W.L. a.m. S.L.		
1.	Atrauli	1.27	0.97	17.0	186	1.6.89	16.2	15.23	169.8	3.11.89	15.08	14.11	170.92	1.12	25°C
2.	Pilkhaunj	1.40	G.L.	16.15	186	"	15.0	15.00	171.0	"	13.9	13.9	172.1	1.10	
3.	Rajmargpur	1.30	0.5	15.0	188	"	15.30	14.8	172.7	"	14.86	14.36	173.1	0.44	
4.	Harcharandpur	1.20	0.5	11.0	186	"	11.60	11.1	174.4	"	11.05	10.55	175	0.6	
5.	Raipur	1.25	0.57	12.50	186	"	12.8	12.23	173.7	"	12.4	11.83	174.24	0.4	
6.	Jirauli	1.0	0.9	12.5	186	"	12.1	11.2	174	"	11.76	10.86	174.2	0.35	
7.	Gobindpur	1.20	0.7	9.67	185	"	9.38	8.68	175.6	"	9.16	8.46	176.54	0.22	
8.	Chakathal	1.0	G.L.	6.90	185	"	6.17	6.17	178.8	"	6.37	6.37	178.63	0.2	
9.	Mohammadpur	1.2	0.7	8.4	183	"	7.5	6.8	175.5	"	6.8	6.1	176.2		
10.	Kheria	1.40	0.1	12.5	186	"	12.15	12.1	173.86	"	11.8	11.7	174.2	0.4	
11.	Bem Birpur	1.0	G.L.	14.0	188	"	12.8	12.8	175.2	"	12.5	12.5	175.5	0.30	
12.	Qasimpur	2.25	0.70	14.7	185	"	14.50	13.8	170.5	"	14.40	13.7	170.6	0.1	
13.	Badauli	1.85	1.5	14.4	186	"	14.3	12.8	171.7	"	14.2	12.9	171.8	0.2	
14.	Gadaipur	2.25	0.7	12.15	186	"	11.80	11.1	174.12	"	11.27	10.57	174.73	0.53	
15.	Basai	1.35	0.5	13.8	187	"	13.5	13	173.5	"	12.95	12.45	174.05	0.55	
16.	Alampur	1.0	0.45	12.60	187	"	12.15	11.7	174.85	4.11.89	11.33	10.88	175.67	0.88	
17.	Lohgarh	1.0	0.55	13.35	186	2.6.89	11.48	10.93	174.5	"	10.85	10.3	175.15	0.63	
18.	Salarpur	1.20	0.45	13	184	"	10.7	10.25	173.3	"	10.58	10.13	173.4	0.12	
19.	Mahera	1.20	0.65	12.20	184	"	10.55	9.9	173.4	"	10.45	9.8	173.55	0.10	
20.	Balipur	1.0	0.7	14	184	"	12.15	11.45	171.8	"	12.08	11.38	171.9	0.07	
21.	Pipri	1.0	0.65	13.5	182	"	10.37	9.72	171.6	"	10.01	9.36	172	0.36	
22.	Lahaski	1.20	0.15	12	184	"	10.47	9.82	173.5	"	10.25	9.6	173.15	0.22	
23.	Gaonkhera	1.20	0.33	14.6	185	"	15	14.67	170.35	"	14.4	14.07	170.93	0.6	
24.	Mahgawan	1.95	0.5	12.2	183	"	12.0	11.5	171	"	11.4	10.9	171.6	0.6	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25.	Muhsanpur	1.15	.45	13.5	185	2.6.89	13.6	13.15	171.4	4.11.89	13.0	12.55	172.45	.6	25°C
26.	Badesra	1.1	0.15	10.9	182	"	10.50	10.35	171.5	"	10.05	9.9	172	0.45	
27.	Badaul	1.5	1.4	12.5	182	"	11.19	9.79	170.81	"	10.7	9.3	171.3	0.5	
28.	Sidh	1.5	0.2	12.0	182	"	9.17	9	172.8	"	8.5	8.3	173.5	0.7	
29.	Bijauli	0.80	0.75	13.76	183	"	13.55	12.8	170.2	"	12.50	11.75	170.5	1.05	
30.	Rumami	1.25	0.90	11.2	182	"	10.7	9.8	171.3	"	10.15	9.25	172.7	0.55	
31.	Singhpur	1.2	0.2	12.0	182	"	11.0	10.8	171	"	10.5	10.3	171.7	0.5	
32.	Sirsa	1.2	0.4	11.3	182	3.6.89	10.68	10.28	171.7	5.11.89	10.4	10.0	171.6	0.3	
33.	Bhuria	1.0	0.4	13.5	183	"	11.7	11.26	171.3	"	10.9	10.5	172.1	0.76	
34.	Charra	1.5	G.L.	14	180	"	12.6	12.5	167.4	"	12.9	12.9	167.1	0.3	
35.	Narauna	1.10	0.40	12.8	182	"	11.8	11.4	170.2	"	11.56	11.13	170.44	0.27	
36.	Chaumoha	1.64	0.45	11.50	183	"	11.4	10.95	171.6	"	11.2	10.75	171.8	0.2	
37.	Mirgarhi	1.2	0.30	12.0	182	"	11.5	11.2	170.5	"	11.1	10.8	171.2	0.4	
38.	Gobli	1.00	0.5	10.5	183	"	9.3	8.8	173.7	"	8.7	8.2	174.8	0.6	
39.	Ahmadpur	1.2	0.45	11.0	182	"	8.8	8.35	173.2	"	8	7.55	174.5	0.8	
40.	Chanduli Buzurg	1.2	G.L.	12.5	182	"	9.6	9.6	172.4	"	9.4	9.4	172.6	0.2	
41.	Surajpur	1.0	0.90	15.0	184	"	13.0	12.1	171	"	12.55	11.65	171.45	0.45	
42.	Pindol	0.55	0.5	8.9	180	"	8.3	7.8	171.7	"	7.6	7.1	172.4	0.7	
43.	Sheikhpur	0.8	0.1	8.0	180	"	7.6	7.5	172.4	"	7.10	7.0	172.9	0.6	
44.	Ganiawli	1.15	0.8	14.6	186	4.6.89	14.6	13.8	171.4	"	14.24	13.44	171.76	0.36	
45.	Fazalpur	2.9	9.55	14.8	186	"	14.8	14.25	171.2	"	14.75	14.2	171.25	0.05	
46.	Alampur	1.7	0.33	15.0	184	"	13.46	13.13	170.5	"	13.33	13.0	170.67	0.13	
47.	Chauchai	1.20	0.20	13.4	182	"	11.85	11.65	170.15	"	11.25	11.05	171.00	0.6	
48.	Gazipur	1.30	0.60	13.47	184	"	13.30	12.7	170.7	"	13.1	12.5	171.5	0.2	
49.	Madapur	0.97	0.8	14.10	184	"	14.15	13.35	169.85	"	14.10	13.3	170	0.05	
50.	Piploi	1.30	0.50	14.1	183	"	13.7	13.2	169.3	"	13.58	13.08	169.42	0.12	
51.	Utra	1.60	0.4	13.30	183	"	13.95	13.45	169.05	"	13.65	13.25	169.35	0.3	
52.	Barla	2.80	0.85	17.32	184	"	15.9	15.05	168.1	"	15.4	14.55	168.6	0.5	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
53.	Arani	1.7	0.8	13.0	181	4.6.89	11.5	10.7	169.5	6.11.89	11.0	10.2	170.0	.5	
54.	Dataoli	1.10	0.25	14.70	181	"	14.7	14.45	166.3	"	14.50	14.25	166.75	0.2	
55.	Chandgarhi	0.80	G.L.	11.50	179	"	10.90	10.90	168.1	"	10.41	10.4	168.6	0.41	
56.	Nosha	0.80	0.30	16.70	184	"	16.40	16.7	167.6	"	16.0	15.7	168.0	0.4	
57.	Sunhera	1.20	0.7	14.40	182	"	13.50	12.8	168.5	"	13.14	12.44	168.86	0.36	
58.	Dhansari	1.00	0.5	12.40	179	5.6.89	12.0	11.5	167	7.11.89	11.17	10.67	168.83	0.83	25^{o}C
59.	Rukhela	0.86	1.0	10.80	179	"	10.17	9.17	168.83	"	9.93	8.93	169.07	0.24	
60.	Gangiri	0.96	0.40	13.45	174	"	12.45	12.05	167.56	"	12.0	11.6	162	0.45	
61.	Dhanisinghpur	1.25	0.45	10.9	178	"	10.0	9.55	168	"	9.6	9.15	168.4	0.4	
62.	Hidramai	1.0	0.1	11.30	178	"	10.8	10.7	167.2	"	10.6	10.5	167.5	0.2	
63.	Mahaula	1.25	1.10	12.8	180	"	12	10.9	168.4	"	11.72	10.62	169.3	0.28	
64.	Malsi	0.9	0.6	10.8	177	"	9.4	8.8	167.1	"	9	8.4	168	0.4	
65.	Bilona	1.25	0.55	9.15	176	"	7.2	6.65	168.8	"	7.13	6.58	168.9	0.07	
66.	Naugawan	1.20	0.8	8.7	180	"	8.3	7.5	171.7	"	7.50	6.7	172.5	0.8	
67.	Nuathal	1.5	1	13	179	"	11.9	10.9	167.1	"	11	10.0	168	0.9	
68.	Tandoli	1.5	0.6	8.25	178	"	7.3	6.7	170.7	"	7	6.4	171	0.30	
69.	Jareth	1.0	0.45	5.4	177	"	5.2	4.7	171.8	"	4.4	3.95	172.6	0.8	
70.	Rajmau	1.2	0.5	5.15	177	"	4.0	3.5	173	"	3.2	2.7	173.8	0.8	
71.	Maoupura	1.2	0.6	8	180	"	7	6.4	173	"	6.4	5.8	173.6	0.6	
72.	Bhikhampur	1.5	0.9	12	180	"	7.95	7.05	172	"	7.31	6.4	172.7	0.64	
73.	Nagla Tolia	0.75	0.30	7.5	180	"	4.5	4.2	175.5	"	4.10	3.8	175.9	0.4	
74.	Nagla Deemer	1.5	0.30	6	179	"	4.2	3.9	174.8	"	3.6	3.3	175.4	0.6	
75.	Bhamori Buzurg	1.00	0.50	9.4	180	"	8.45	8	171.5	8.11.89	8.05	7.55	172	0.4	
76.	Ata	1.1	0.2	8	180	6.6.89	6.46	6.26	173.5	"	6.30	6.1	173.7	0.16	24^{o}C
77.	Dadon	1.1	0.5	7	180	"	5.8	5.3	174.2	"	5.0	4.5	175	0.5	
78.	Bhur Ka Nagla	1.0	0.2	8	181	"	5.9	5.7	175.1	"	5.3	5.1	175.7	0.6	
79.	Alampur	1.2	0.4	7.5	180	"	4.56	4.16	175.4	"	4.16	3.76	175.85	0.4	
80.	Sarak Ka Nagla	1.2	0.4	8.5	182	"	7.15	6.75	174.85	"	5.80	5.4	176.2	0.95	
81.	Lehra	1.0	0.6	9.0	182	"	5.85	5.25	176.15	"	5.4	4.8	176.6	0.45	
82.	Shamshpur Katra	0.75	0.25	8.5	184	"	6.0	5.75	178	"	5.5	5.25	178.5	0.5	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
83.	Sankra	1.25	0.4	8.0	177	6.6.89	5.85	5.45	171.15	8.11.89	5.30	4.9	171.7	0.5	23°C
84.	Dinapur	0.95	0.35	4.5	175	"	2	1.65	173	"	1.5	1.15	173.5	0.50	
85.	Todarpur	0.95	0.35	5	176	"	3.1	2.75	172.9	"	2.35	2	173.7	0.7	
86.	Gangbas	1.0	0.4	6.5	176	"	2.3	1.9	173.7	"	1.8	1.4	174.2	0.5	
87.	Ismailpur	1	0.7	4	171	"	3.95	3.25	167.07	"	3.35	2.65	167.5	0.6	
88.	Gopalpur	1.2	0.5	4	171	"	2.6	2.1	168.4	"	1.95	1.45	169.05	0.65	
89.	Kanchanpur	1.0	0.45	5	172	"	2.50	2.05	169.5	"	2.1	1.65	169.9	0.4	
90.	Mokhimpur	1.0	0.35	6.5	180	"	3.0	2.65	177	"	2.4	2.05	177.6	0.6	
91.	Piaoli	1.2	0.35	6	181	7.6.89	3.7	3.4	177.3	9.11.89	3.10	2.75	177.25	0.65	
92.	Narupura	1.0	0.5	9	182	"	7.6	6.9	174.4	"	6.85	6.35	175.1	0.5	24°C
93.	Bhojpur	0.9	0.6	6	180	"	5	4.4	175	"	4.7	4.1	175.3	0.3	
94.	Hardoi	1.8	0.8	8	184	"	6.7	5.9	177.3	"	6.10	5.3	177.9	0.6	
95.	Dattacholi	0.9	0.2	10	181	"	7.2	7	173.8	"	6.5	6.3	174.5	0.7	
96.	Bahanakotra	1	0.45	8.5	180	"	5.0	4.55	175.4	"	4.6	4.15	175.85	0.4R	
97.	Khandwa	1.0	0.35	6	180	"	3.6	3.25	176.4	"	2.6	2.35	177.4	0.9	
98.	Kotra	1.30	0.35	6.1	171	8.6.89	2.1	1.75	168.9	10.11.89	1.8	1.45	169.2	0.3	
99.	Jakhurdarpur	1.2	0.6	9.5	175	"	8.1	7.5	166.9	"	7.4	6.8	168.2	0.7	
100.	Mamon	1.5	0.4	8.0	171	"	7.35	6.95	163.6	"	7.30	6.9	163.7	0.05	
101.	Gorha	1.8	0.75	7.70	171	"	7.15	6.4	163.85	"	6.55	5.8	164.55	0.6	
102.	Narauli	1.0	0.8	7.6	171	"	5.45	4.65	165.5	"	5.05	4.25	165.95	0.4	25°C
103.	Kisrauli	1.6	0.5	7.1	174	"	4.9	4.4	169	"	4.60	4.1	169.4	0.3	
104.	Maharajpur	2.0	0.3	1.7	175	"	4.8	4.5	170.2	"	4.4	4.1	170.6	0.04	
105.	Barwarikalan	1.70	0.45	6.7	175	"	4.5	4	170.5	"	4.15	3.7	170.85	0.3	
106.	Kasganj	1.5	1	14.4	172	"	8.35	7.35	163.65	"	8.10	7.1	163.9	0.25	
107.	Namaini	1.10	1.4	8	177	9.6.89	6.72	5.32	170.2	12.11.89	6.25	4.85	170.75	0.47	
108.	Kindi	1.8	0.2	7.1	176	"	5.85	5.65	170.15	"	5.35	5.15	170.85	0.5	
109.	Kumrauwa	1.5	0.8	8.8	17.7	"	7.5	6.7	169.5	"	6.7	5.9	170.3	0.8	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
110.	Pachnala	1.15	0.5	6.2	176	9.6.89	5.85	5.35	170.15	12.11.89	5.60	5.10	170.9	0.15	25°C
111.	Ismailpur	1.0	0.70	4	171	"	3.95	3.25	167.05	"	3.35	2.65	167.65	0.6	
112.	Sirauli	1.65	0.6	9.2	172	"	8.45	7.85	163.55	"	7.75	7.15	164.5	0.7	
113.	Chandaus	1.2	0.4	0.4	172	"	4.8	4.4	167.2	"	4.2	3.8	168.2	1.0	
114.	Siapur	1.1	0.45	5.5	170	"	4.8	4.35	165.2	"	3.9	3.45	166.1	0.9	
115.	Saleempur	1.0	0.23	6	170	"	3.75	3.52	166.2	"	3.15	2.92	167.08	0.6	
116.	Bahaupur	1.2	0.65	6	170	"	3.55	2.9	166.45	"	3.10	2.45	166.9	0.45	
117.	Fatehpur Kalan	1.10	0.65	5		"	3.95	3.3	165	"	3.45	2.8	165.55	0.5	
118.	Soron	1.30	0.60	10	172	"	8.5	7.9	164.1	"	8.35	7.75	163.65	0.15	
119.	Kardarbari	1.2	0.5	5	175	"	3.75	3.25	171.2	"	3.3	2.8	172.2	0.42	
120.	Jareth	1	0.30	5	167	10.6.89	3.8	3.5	163.2	"	3.2	2.9	163.8	0.6	
121.	Banupur	1.2	0.7	5	166	"	3.2	2.5	162.8	"	2.70	2.0	163.3	0.5	
122.	Braudha	1.0	0.6	5	168	"	4.2	3.6	163.8	"	3.6	3.0	165.0	0.6	
123.	Thathepur	1.2	0.7	5.5	168	"	3.10	2.4	164.9	"	2.7	2.7	165.3	0.4	
124.	Hodalpur	1.00	0.7	5.9	168	"	4.65	3.95	163.3	13.11.89	3.6	2.9	164.4	0.96	
125.	Nagla Khanji	1.3	0.73	7.9	175	"	9.5	8.77	165.5	"	9.35	8.62	165.65	0.15	
126.	Khairpur	1.2	1.0	10.0	179	"	9.5	8.5	169.5	"	9.0	8.0	170.0	0.5	
127.	Nagla Bari	1.3	0.7	6.0	170	"	2.85	2.15	167.15	"	2.2	1.5	167.8	0.65	
128.	Barkula	1.2	0.6	7.5	170	"	4	3.4	166	"	3.10	2.5	166.9	0.9	
129.	Daniyalganj	0.9	9.5	5.8	172	"	4.5	4	167.5	14.11.89	4.2	3.7	168.3	0.3	
130.	Nagla Bidhai	2.5	0.5	6.0	170	11.6.89	3.8	3.3	166.2	"	3.6	3.1	166.4	0.2	
131.	Jakhera	1.0	0.55	9.3	173	"	9.30	8.75	163.7	"	8.05	7.5	164.95	1.25	
132.	Saleempur	1.0	0.5	10.6	175	"	9.63	9.13	165.37	"	9.35	8.85	165.87	0.28	
133.	Satpura	1.0	0.3	9.6	176	"	8.9	8.6	167.1	"	8.75	7.65	167.25	0.15	
134.	Bilram	1.30	0.8	13.0	177	"	9.13	8.33	167	"	8.45	7.65	168.55	0.68	
135.	Rahmatpur	1.2	0.6	8.4	177	"	7.3	6.7	169.7	"	7	6.4	170	0.68	
136.	Naugawan	1.1	0.45	6	175	"	4.7	4.25	170.3	"	4.1	3.65	170.9	0.60	
137.	Barhera	1.8	0.5	11.0	176	"	9.45	8.95	166.55	"	9.30	8.8	166.7	0.15	
138.	Firozpur	1.3	0.6	10.5	175	"	9.1	8.5	166	"	8.95	8.35	166.0	0.15	
139.	Firozpur Suhela	1.3	G.L.	7.8	175	"	7	7	168	"	6.7	6.7	168.3	0.3	
140.	Karsari	1.15	0.65	11.5	176	"	8.6	7.95	167.4	"	8.1	7.45	167.9	0.4	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
141.	Dholna	1.7	0.25	9.8	176	11.6.89	8.9	8.65	167.1	13.11.89	8.15	7.9	167.9	0.75	25°C
142.	Wahidpur	2.1	0.45	9.5	177	12.6.89	8.7	8.25	168.3	"	8.8	8.35	168.2	0.1	
143.	Kanawa	1.2	0.3	7.0	174	"	6.0	5.7	168	"	5.2	4.9	168.8	0.8	
144.	Chhara	1.3	0.6	7.0	177	"	4.26	3.66	172.7	"	3.5	3.0	173.5	0.76	
145.	Ikhauna	1.2	0.3	6.10	177	"	5	4.7	172	"	3.8	3.5	173.2	1.2	
146.	Ghinauna	1.2	0.5	5.3	175	"	4.45	3.95	170.55	"	3.65	3.15	171.35	0.8	
147.	Garhi H.	1.0	0.8	5	175	"	3.95	3.1	171	"	2.65	1.85	172.4	1.25	
148.	Akbarpur	2.2	0.7	5	175	"	4.4	3.7	170.6	"	3.55	2.8	171.5	0.9	
149.	Nagla Amber	2.4	0.7	4.3	176	"	3.8	3.10	172.2	"	2.8	2.1	173.2	1.0	
150.	Tabalpur	1.0	0.5	8	174	"	4.65	4.15	169.3	"	3.9	3.4	170.1	1.05	
151.	Nagla Dhak	1.3	0.4	6	177	"	4.15	3.75	172.85	"	3.5	3.1	173.9	0.65	
152.	Kaser	1.0	0.5	6.5	178	13.6.89	4.7	4.2	173.3	"	3.9	3.4	174.1	0.8	
153.	Ajwanther	1.1	0.5	4	180	"	3.1	2.6	177	15.11.89	2.25	1.75	177.75	0.85	
154.	Begpur	1.2	0.4	5.5	180	"	2.6	2.2	177.4	"	2.0	1.6	178	0.6	
155.	Nagla Moti	1.0	0.35	6	178	"	4.5	4.15	173.5	"	3.8	3.45	174.2	0.7	
156.	Khudar	1.3	0.4	5.6	178	"	4.7	4.3	173.3	"	4.10	3.7	174.3	0.6	

APPENDIX - V

Shows the Piezometric Level

Location	R.L.	Piezometric Levels	Piezometric surface(a.m.SL)
Atrauli	186	8.62	177.3
Gobli	183	7.2	175.8
Narauna	183	6.1	176.5
Husainpur	182	10.5	171.5
Bidhari	174	10.76	163.0
Chakathal	186	5.6	180.4
Barla	184	12.0	172.0
Khoria	186	5.6	180.0
Qasimpur	186	7.62	177.38
Utra	183	8.0	175.0
Pali	185	9.14	175.6
Logharh	186	7.62	178.38
Habibpur	180	10.06	170.0
Arni	181	8.0	173.0
Rukhela	179	9.6	169.4
Bainkalan	179	6.4	173.6
Bhamori Buzurg	180	5.7	174.3
Bijauli	183	8.53	174.47
Pithanpur	184	6.4	177.6
Kamsai	182	8.0	174.0
Dhansari	179	9.76	169.24

Location	R.L.	Piezometric levels	Piezometric surface (a.m.S.L.)
Ghinauna	175	5.5	169.5
Sirawli	1172	10.5	166.5
Namaini	177	3.0	174.0
Fatehpur	169	10.0	159.0
Nagla Khanji	175	9.15	165.85
Mehewa Kalan	177	5.5	171.5
Narauli	171	3.0	168.0
Kasganj	172	5.1	167.0
Bilram	177	8.0	169.0

APPENDIX - VI

Showing the values of Transmissivity (T), Permeability (K) and Specific Capacity Index, tabulated as per Logan's (1964) formula

Location	Thickness of aquifer tapped	Discharge m^3/day	Draw down (m)	Specific capacity m^2/day	Transmissivity m^2/day	Permeability m/day	Yield factor m/day
Gobli	42.98	4486.32	4.87	921.21	1123.88	26.14	21.43
Narauna	34.45	3975.6	5.5	722.83	881.86	25.59	21.0
Husainpur	18.59	2086.56	5.5	379.37	462.83	24.89	20.4
Chakathal	30.0	3975.6	5.5	722.8	881.86	29.40	24.09
Gangiri	26.2	3207.6	2.43	1320 .0	1610.4	61.5	50.38
Barla	19.23	4313.52	5.5	784.27	956.81	49.75	40.78
Fusawali	27.75	3823.2	5.5	695.12	848.05	30.56	25.04
Kheria	29.4	4847.04	7.01	692.43	844.76	28.73	23.55
Utra	21.2	5205.6	5.8	897.51	1094.96	51.6	42.33
Tevtu	25.6	2942.4	5.25	560.45	683.75	26.70	21.89
Pali	62.7	5824.8	3.65	1595.83	1946.9	31.05	25.45
Salarpur	37.48	2937.6	7.3	402.40	490.94	13.0	10.73
Lohgarh	34.87	6120.0	5.5	1112.72	1357.52	38.93	31.9
Badaul	26.2	3006.7	3.65	823.75	1004.98	38.35	31.4
Habibpur	29.57	3909.6	5.5	710.83	867.22	29.32	24.0
Chabilpur	21.0	3034.8	5.5	551.78	673.17	32.05	26.27
Arni	40.5	3965.28	4.0	991.32	1209.41	29.86	24.47
Tikta	30.5	4250.88	6.7	634.45	774.04	25.37	20.80
Rukhela	58.54	8586.0	4.95	1734.54	2116.14	36.14	20.62
Bhamori Buzurg	30.02	4485.0	7.0	640.0	781.77	26.05	21.33
Bijauli	*20.73*	*2592.0*	3.4	762.35	930.07	*44.86*	36.75
Pithanpur	40.8	4968.0	6.09	828.0	1010.16	24.75	20.3
Nagla Kamsai	30.0	3130.32	3.65	857.62	1046.29	34.89	28.58
Dhansari	21.3	3820.8	7.2	530.66	647.4	30.35	24.90
Ghinauna	45.36	7838.2	7.0	1119.74	1366.0	30.11	24.68
Sirawali	34.43	5949.5	7.0	849.92	1036.9	30.11	24.68

Location	Thickness of aquifer tapped	Discharge m^3/day	Drawn down (m)	Specific capacity m^2/day	Transmissivity m^2/day	Permeability m/day	Yield factor m/day
Nameni	33.6	5799.16	4.95	1171.54	1429.28	42.5	34.86
Nagla Khanji	41.56	5984.6	7.0	854.94	1043.03	25.09	20.6
Siapur	31.5	4995.27	5.18	964.38	1176.49	37.34	30.6
Mahawa Kalan	49.5	8553.6	6.7	1276.65	1557.52	31.46	25.79
Narauli	39.67	3630.33	5.0	726.0	885.80	22.32	18.3
Mamu	30.36	4809.02	5.0	961.8	1173.4	38.6	31.67
Birsua	46.71	6726.2	3.35	2007.82	2449.54	52.44	43.0
Begpur	37.0	4924.8	7.0	703.5	858.32	23.19	19.01
Soron	31.46	2880.0	3.81	755.9	922.2	29.31	24.02
Bilram	28.64	2592.0	4.9	528.97	645.35	22.53	18.5
Jamona	33.5	2937.6	3.6	816.0	995.5	29.7	24.35
Bhabhigarhi	25.30	3542.4	6.5	544.98	664.88	26.27	21.54
Piaoli	36.17	4654.8	8.2	565.58	690.01	19.07	15.63
Gazipur	25.8	4924.8	7.31	673.7	821.9	31.8	26.1
Kazimabad	28.8	6123.6	3.04	2041.2	2490.26	86.46	70.87
Atrauli	26.13	4860.0	5.0	972.0	1185.85	45.38	37 2
Sunhora	20.12	4228.09	7.31	578.4	705.6	35.07	28.74
Nosha	30.7	3365.4	5.8	580.24	707.89	23.05	18.9
Qasimpur	15.77	2192.4	5.3	413.7	504.7	31.5	26.18
Naugaon	35.0	6123.0	10.5	588.80	718.35	20.52	16.82
Kasganj	26.99	2664.0	4.26	625.35	762.92	28.25	23.10
Salcompur	39.72	4841.0	2.13	2272.76	2772.6	69.8	57 21
Naugaon	40	4313.5	7.62	566.07	690.6	17.26	14.10

APPENDIX - VII (A)

Pump Test Data of Paharipur

OBSERVATIONS DURING PUMPING

TIME IN HOURS	TIME IN MINUTES	DRAW - DOWN IN MAIN WELL	OBS. WELL	REMARKS
22.0	0	0.00	0.00	Pump started
22.005	0.5	6.90	0.03	
22.01	1	7.60	0.05	
22.015	1.5	7.76	0.07	
22.02	2	7.835	0.085	
22.025	2.5	7.925	0.09	
22.03	3	7.985	0.105	
22.04	4	8.05	0.115	
22.05	5	8.08	0.125	
22.06	6	8.08	0.135	
22.07	7	8.08	0.135	
22.08	8	8.085	0.14	
22.09	9	8.095	0.145	
22.10	10	8.10	0.15	
22.12	12	8.11	0.155	
22.14	14	8.10	0.16	
22.16	16	8.135	0.16	
22.18	18	8.125	0.165	

TIME IN HOURS	TIME IN MINUTES	DRAW - DOWN IN MAIN WELL	OBS. WELL	REMARKS
22.20	20	8.125	0.17	
22.25	25	8.285	0.175	
22.30	30	8.26	0.18	
22.35	35	8.29	0.185	
22.40	40	8.31	0.19	
22.45	45	8.375	0.195	
22.50	50	8.555	0.20	
22.55	55	8.60	0.21	
23.00	60	8.62	0.22	
23.10	70	8.565	0.225	
23.20	80	8.395	0.23	
23.30	90	8.34	0.24	
23.40	100	8.53	0.25	
23.50	110	8.62	0.255	
24.00	120	8.65	0.265	
0.30	150	8.815	0.27	
1.00	180	8.34	0.30	
1.30	210	8.89	0.30	
2.00	240	8.64	0.30	
2.30	270	8.60	0.30	
3.00	300	8.62	0.315	
3.30	330	8.67	0.315	

TIME IN HOURS	TIME IN MINUTES	DRAW - MAIN WELL	DOWN IN OBS. WELL	REMARKS
4.00	360	8.605	0.32	
4.40	400	8.435	0.33	
5.30	450	8.365	0.335	
6.20	500	8.485	0.34	
7.10	550	8.562	0.35	Power cut for 5 second
8.00	600	8.95	0.355	
8.50	650	8.575	0.36	
9.40	700	8.68	0.37	
11.20	800	8.56	0.38	
13.00	900	8.625	0.395	
14.40	1000	8.56	0.41	
1620	1100	8.585	0.415	
18.00	1200	8.80	0.43	
19.440	1300	8.40	0.44	
23.00	1500	8.74	0.45	Power cut for 5"
0.45	1605	8.75	0.45	Pump stopped

APPENDIX - VII (B)

Pump test data of Danpur

Sl. No.	Time (t) since pumping started in minutes.	Draw down observed in different observation wells (in metres)	
		Obs. well No. 1	Obs. well No.2
1	2	3	4
1.	0.0	0.0	0.0
2.	0.5	0.07	0.0
3.	1.0	0.11	0.0
4.	1.5	0.13	0.035
5.	2.0	0.14	0.040
6.	2.5	0.16	0.05
7.	3.0	0.16	0.06
8.	3.5	0.17	0.065
9.	4.0	0.175	0.07
10.	4.5	0.18	0.07
11.	5.0	0.18	0.075
12.	5.5	0.19	0.075
13.	6.0	0.19	0.08
14.	6.5	0.195	0.085
15.	7.0	0.200	0.09
16.	7.5	0.200	0.09
17.	8.0	0.205	0.09
18.	8.5	0.205	0.095

1	2	3	4
19.	9.0	0.205	0.095
20.	9.5	0.205	0.100
21.	10.0	0.21	0.100
22.	11.0	0.22	0.105
23.	12.0	0.22	0.105
24.	13.0	0.225	0.11
25.	14.0	0.23	0.11
26.	15.0	0.23	0.115
27.	16.0	0.23	0.12
28.	17.0	0.235	0.125
29.	18.0	0.24	0.125
30.	19.0	0.24	0.13
31.	20.0	0.245	0.13
32.	21.0	0.25	0.13
33.	22.0	0.25	0.135
34.	23.0	0.25	0.135
35.	24.0	0.25	0.140
36.	25.0	0.255	0.14
37.	26.0	0.26	0.145
38.	27.0	0.26	0.145
39.	28.0	0.26	0.15
40.	29.0	0.26	0.15
41.	30.0	0.265	0.15
42.	32.	0.265	0.155

1	2	3	4
43.	34.0	0.27	0.16
44.	36.0	0.27	0.16
45.	38.0	0.27	0.16
46.	40.0	0.27	0.16
47.	42.0	0.28	0.165
48.	44.0	0.28	0.17
49.	46.0	0.28	0.17
50.	48.0	0.28	0.17
51.	50.0	0.28	0.175
52.	52.0	0.28	0.175
53.	54.0	0.28	0.18
54.	56.0	0.28	0.18
55.	58.0	0.29	0.18
56.	60.0	0.29	0.18
57.	65.0	0.30	0.19
58.	70.0	0.31	0.19
59.	75.0	0.31	0.195
60.	80.0	0.315	0.20
61.	85.0	0.32	0.20
62.	90.0	0.32	0.20
63.	95.0	0.32	0.21
64.	100.0	0.325	0.215
65.	105.0	0.32	0.22

1	2	3	4
66.	110.0	0.325	0.22
67.	115.0	0.33	0.22
68.	120.0	0.335	0.22
69.	125.0	0.335	0.22
70.	130.0	0.34	0.22
71.	135.0	0.34	0.22
72.	140.0	0.345	0.22
73.	145.0	0.345	0.225
74.	150.0	0.345	0.225
75.	160.0	0.345	0.23
76.	170.0	0.35	0.235
77.	180.0	0.355	0.235
78.	190.0	0.36	0.235
79.	200.0	0.36	0.24
80.	210.0	0.37	0.245
81.	220.0	0.37	0.245
82.	230.0	0.37	0.25
83.	240.0	0.37	0.25
84.	250.0	0.38	0.255
85.	260.0	0.38	0.255
86.	270.0	0.38	0.255
87.	280.0	0.38	0.255
88.	290.0	0.385	0.26

1	2	3	4
89.	300.0	0.385	0.26
90.	320.0	0.39	0.26
91.	340.0	0.385	0.265
92.	360.0	0.40	0.265
93.	380.0	0.40	0.275
94.	400.0	0.40	0.28
95.	420.0	0.40	0.28
96.	440.0	0.41	0.28
97.	460.0	0.415	0.285
98.	480.0	0.415	0.285
99.	500.0	0.415	0.285
100.	520.0	0.415	0.29
101.	540.0	0.415	0.29
102.	560.0	0.415	0.29
103.	580.0	0.415	0.29
104.	600.0	0.415	0.29
105.	620.0	0.415	0.29
106.	640.0	0.415	0.29
107.	660.0	0.42	0.30
108.	680.0	0.42	0.30
109.	700.0	0.425	0.30
110.	720.0	0.425	0.30
111.	740.0	0.425	0.30
112.	760.0	0.425	0.30

1	2	3	4
113.	780.0	0.425	0.30
114.	800.0	0.415	0.30
115.	820.0	0.405	0.295
116.	840.0	0.405	0.295
117.	860.0	0.42	0.30
118.	880.0	0.42	0.30
119.	900.0	0.415	0.305
120.	920.0	0.415	0.305
121.	940.0	0.405	0.30
122.	960.0	0.405	0.30
123.	980.0	0.415	0.31
124.	1000.0	0.42	0.31
125.	1020.0	0.42	0.31
126.	1040.0	0.42	0.31
127.	1060.0	0.405	0.31
128.	1080.0	0.405	0.31
129.	1100.0	0.405	0.31
130.	1120.0	0.365	0.27
131.	1140.0	0.37	0.27
132.	1160.0	0.36	0.26
133.	1180.0	0.35	0.355
134.	1200.0	0.31	0.25
135.	1220.0	0.31	0.24
136.	1240.0	0.31	0.24

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APPENDIX - VIII (A)

Results of partial chemical analysis of water samples collected from dug-wells of Ganga-Kali sub-basin during 1988.

(Results in mg/l)

Sl. No.	Location	pH	E.C. umoh/cm	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Na^+	K^+	Ca^+	Mg^{++}	T.D.S.	Total hardness
1.	Rajmargpur	8.8	665	8	274	100	140	70	37	46	28	430	186
2.	Ganeshpur	8.8	470	10	240	45	120	88	15	30.6	20	310	160
3.	Basai	8.7	344	17	247	26.62	69.95	44.6	14.36	29.24	25	220	200
4.	Logarh	7.6	609	18	345	96	65	46	33	59	54	390	360
5.	Mahera	7.3	898	12	592	120.7	96	59	17 66	48	67.68	575	300
6.	Bijauli	7.6	842	12	497	106	85	142.6	31.56	50	41.4	542	290
7.	Bhamoribuzurg	7.6	423	3	342	46	54	61.27	37	36	38	300	. 200
8.	Charra	8.8	379	15	290	35.5	98	80	17.6	30	20	243	155
9.	Barla	8.8	713	10	260	74	271	49	76.5	55.2	24.5	460	188
10.	Chandgarhi	8.0	610	8	340	53	136	132	18	30	20	390	140
11.	Sunhera	8.8	550	18	255	44	127	58	85	38	21	350	160
12.	Madapur	8.0	367	-	380	28	160	50	15.3	60	30	235	200
13.	Piploi	7.8	556	6	339	58.1	75	102	19.18	37.2	30	360	220
14.	Ganiwali	8.0	700	8	274	100	140	70	37	46	28	430	150
15.	Surajpur	7.6	303	-	230	53	75	33	25	30	24	200	170
16.	Atrauli	8.4	500	8	300	60	85	75	25	41	27	315	210
17.	Chaumuhan	8.6	481	7	274	53	100	72	28.4	40	25	308	175
18.	Ghazipur	7.8	329	9	265	56.8	80	87.6	44	34	30	215	210
19.	Rukhela	8.3	600	15	424	26.6	140	150	42.04	42.8	23	385	225
20.	Gangiri	8.5	620	10	410	30.8	125	95	35	40	25	390	200
21.	Hidramai	7.8	613	6	403	106	180	85.0	18.9	60	72	400	146
22.	Jareth	7.4	261	28	216	60.35	75	30	8.3	49.26	45.18	200	146.66
23.	Naugaon	8.8	450	-	244	17.8	150	28	23	40 4	23	280	230
24.	Ikhauna	8.9	850	21	310	17.75	210	108	31.34	40.84	30	545	233
25.	Ghinauna	8.0	700	9	393	26.6	11 0	35	35 72	74	40	450	350
26.	Garhi	7.6	780	9	385	80	70	148	11.7	35	20.94	500	200
27.	Bilram	8.78	318	14	290	26.8	150	49.05	10.26	65.7	14	210	220
28.	Kasganj	8.4	733	9	226	95	146	78	33 8	61	30	470	300
29.	Narauli	8 7	422	10	360	35.5	110	57	45	57	36.6	300	200
30.	Namaini	8.3	692	8	485	28	144	76	71	39	22	425	180
31.	Kindi	7.4	668	-	418	85	48	47	26.18	39	68	440	200
32.	Khairpur	8.6	400	5	183	26.6	128	35	15	45	20	350	195
33.	Gorha	8.0	750	15	351	36	100	38	59	34	32	500	180
34.	Wahidpur	8.6	264	6	177	17.75	164	28	26	45	22	200	180
35.	Saleempur	8.8	307	30	300	30 17	160	45 81	8	68.41	23 29	200	333
36.	Soron	8.0	499	19	340	35	110	55	8	32	22	320	170
37.	Sirawali	8.6	274	14	280	26.6	180	34	44	52	35	250	173 3
38.	Ismailpur	7.8	488	36	541	42.6	80	73.5	12.48	36	30 2	315	160
39.	Sankra	8.3	1500	-	410	186	43	89.4	51	46.9	36.4	950	160
40.	Todarpur	7.7	360	-	279	53	90	79	12.9	30.56	26	230	160
41.	Dinapur	7.5	315	6	244	46	94	13.18	55	64	27.4	250	170

APPENDIX - VIII (B)

Results of partial chemical analysis of water samples collected from Dug-wells of Ganga-Kali sub-basin during 1988.

(Results in Epm)

Sl. No.	Location	pH	E.C.	CO_3^{--}	HCO_3^{--}	Cl^-	SO_4^{--}	Total	Na^+	K^+	Ca^{++}	Mg^{++}	Total	Na%	SAR	R.C.
1.	Rajmargpur	8.8	665	0.26	4.49	2.82	2.91	10.48	3.04	0.95	2.30	2.30	8.6	46.4	2.0	0.15
2.	Ganeshpur	8.7	470	0.3	3.9	1.26	2.5	7.96	3.82	0.38	1.53	1.64	7.37	56.98	3.0	1.03
3.	Basai	8.7	344	0.56	4.0	0.75	1.45	6.76	1.93	0.36	1.46	2.05	5.8	38.2	1.45	0.99
4.	Lohgarh	7.6	609	0.6	5.65	2.70	1.35	10.30	2.00	0.84	2.94	4.40	10.18	28.0	1.48	1.09
5.	Mahera	7.3	898	0.4	9.7	3.40	2.0	15.58	2.56	0.48	2.39	5.57	11.0	27.6	1.28	2.14
6.	Bijauli	7.6	848	0.4	8.14	2.98	1.76	13.28	6.2	0.80	2.49	3.4	12.9	53.84	3.61	2.65
7.	Bhamori Buzurg	7.6	423	0.1	5.6	1.29	1.12	8.1	2.66	0.94	1.79	2.71	8.1	44.0	1.8	1.2
8.	Charra	8.8	379	0.5	4.75	1.00	2.04	8.29	3.4	0.45	1.5	1.64	7.0	51.3	2.7	2.11
9.	Barla	8.8	713	0.3	4.2	2.08	5.64	12.2	2.56	1.96	2.74	2.02	9.28	48.09	1.7	0.26
10.	Changarhi	8.0	610	0.26	5.57	1.49	2.83	10.15	5.7	0.46	1.49	1.64	9.3	66.30	4.55	2.70
11.	Sanhera	8.8	550	0.6	4.09	1.24	2.64	8.57	2.60	2.17	1.9	1.8	8.47	56.31	1.91	0.99
12.	Madapur	8.0	367	-	6.24	0.78	3.4	10.43	2.17	0.39	3.0	2.46	8.0	32.00	1.31	0.78
13.	Piploi	7.8	556	0.2	5.5	1.63	1.56	8.89	2.74	0.49	1.85	2.46	7.54	42.5	1.86	1.39
14.	Ganiawali	8.8	700	0.26	4.42	1.71	1.87	8.26	4.46	0.64	1.29	1.80	8.19	62.27	3.5	1.59
15.	Surajpur	7.6	303	-	3.76	1.49	1.56	6.81	1.43	0.64	1.49	1.97	5.53	37.0	1.08	0.15
16.	Atrauli	8.4	500	0.13	4.91	1.69	1.76	8.49	3.26	0.63	2.04	2.22	8.15	40.36	2.24	0.80
17.	Chaumuhan	8.6	481	0.23	4.49	1.49	2.08	8.29	3.13	0.73	2.00	2.05	7.9	48.00	2.2	0.67

Sl. No.	Location	pH	E.C.	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Total	Na^+	K^+	Ca^{++}	Mg^{++}	Total	Na%	SAR	R.C.
18.	Ghazipur	7.8	329	0.30	4.34	1.60	1.66	7.90	1.43	1.12	1.69	2.50	6.74	37.50	0.98	0.49
19.	Rukhela	8.3	600	0.48	6.95	0.75	3.74	11.92	6.52	1.08	2.17	1.89	11.66	65.00	4.57	3.37
20.	Gangiri	7.8	620	0.03	6.71	0.86	2.60	10.20	4.13	0.89	1.99	2.05	9.06	55.40	2.90	2.69
21.	Hidramai	7.8	613	0.20	6.60	2.98	3.74	13.52	3.69	0.48	3.30	5.90	13.37	31.18	1.77	2.20
22.	Jareth	7.4	261	0.92	3.54	1.70	1.55	7.71	1.30	0.21	2.5	3.7	7.71	19.58	3.61	2.65
23.	Naugaon	8.8	235	-	3.99	0.5	2.49	6.98	1.21	0.58	2.01	1.89	5.69	31.45	0.87	0.09
24.	Ikhauna	8.8	850	0.7	5.08	0.5	4.37	10.65	4.7	0.8	2.03	2.46	10.00	55.00	3.13	1.29
25.	Ghinauna	8.0	700	0.3	6.06	0.75	2.29	9.4	1.52	0.91	3.7	3.29	9.4	28.85	0.8	0.63
26.	Garhi	7.61	780	0.3	6.30	2.25	1.45	10.3	6.4	0.3	1.74	1.72	10.16	65.00	4.86	3.14
27.	Bilram	8.78	318	0.46	4.75	0.75	3.12	9.08	2.13	0.77	3.27	1.15	7.34	39.5	1.43	0.79
28.	Kasganj	8.40	733	0.4	4.5	2.27	2.6	9.7	3.85	0.86	2.8	2.0	9.7	44.0	2.48	0.00
29.	Narauli	8.7	422	0.3	5.73	1.0	2.3	9.33	2.4	1.15	2.84	3.0	9.39	1.40	3.78	0.19
30.	Namaini	8.3	692	0.26	7.90	0.80	2.90	11.86	3.29	1.8	1.9	1.8	8.79	50.0	2.40	4.46
31.	Kindi	7.40	668	-	6.95	2.38	1.00	10.23	2.44	0.87	1.94	4.8	10.05	33.0	1.32	0.21
32.	Khairpur	8.6	253	0.16	3.00	0.76	2.66	6.58	1.52	0.64	2.25	1.64	6.05	35.7	1.0	0.73
33.	Gorha	7.6	780	0.5	5.75	1.01	2.08	9.3	1.7	1.5	1.7	2.63	7.53	40.00	1.15	1.92
34.	Wahidpur	8.6	264	0.20	2.9	0.5	3.38	6.98	1.21	0.66	2.24	1.80	5.91	31.64	0.85	-
35.	Saleempur	8.8	307	1.00	4.9	0.85	2.9	9.65	1.99	0.2	3.41	1.89	7.49	27.00	1.00	0.60
36.	Soron	8.0	499	0.63	5.57	1.00	0.29	9.50	3.40	1.22	2.6	1.8	9.02	51.2	1.84	2.8
37.	Sirawali	8.6	274	0.46	4.58	0.75	3.74	9.53	1.47	1.13	2.6	2.87	8.07	33.00	1.50	0.40
38.	Ismailpur	7.8	488	1.2	8.86	1.20	1.66	12.92	3.2	0.32	1.8	2.48	7.8	45.00	2.18	5.78
39.	Sankra	8.3	1500	-	6.71	5.24	0.9	12.85	3.88	1.30	2.34	2.99	10.5	49.30	2.38	1.38
40.	Todarpur	7.7	360	0.2	4.57	1.49	1.87	8.13	1.56	0.33	1.32	2.13	5.34	35	1.18	1.32
41.	Dinapur	7.5	315	0.2	4.00	1.3	1.95	7.45	0.57	1.41	3.19	2.25	7.42	27	0.34	1.24

*Residual carbonate

APPENDIX - IX (A)

Trace element data of the water samples collected from dug well.

(Results mg/litre)

Sl. No.	Location	Fe	Pb	Zn	Cu	Cd	Cr	Mn	Sr	Li
1.	Rajmargpur	0.353	0.4902	0.081	0.026	0.0264	0.0451	0.180	2.078	0.032
2.	Ganeshpur	0.063	0.1735	0.040	0.027	0.0164	0.0429	0.054	1.20	0.021
3.	Lohgarh	0.048	0.1651	0.051	0.021	0.0146	0.0246	0.015	0.801	0.034
4.	Ganiawali	0.372	0.1207	0.069	0.020	0.0186	0.0472	0.049	1.402	0.035
5.	Gazipur	0.030	0.0603	0.017	0.011	0.0151	0.0290	0.030	0.168	0.017
6.	Madapur	0.234	0.2338	0.206	0.027	0.0353	0.0601	0.023	0.945	0.022
7.	Barla	0.099	0.1056	0.114	0.055	0.0153	0.0386	0.032	1.424	0.028
8.	Sunhera	0.386	0.0679	0.122	0.074	0.0173	0.0429	0.026	0.642	0.025
9.	Sherpur	-	0.2036	0.11	0.029	0.0130	0.0397	0.013	-	0.032
10.	Rukhela	1.021	0.1961	0.081	0.038	0.0181	0.0408	0.163	0.777	0.036
11.	Gangiri	0.501	0.1357	0.104	0.030	0.0143	0.0418	0.021	0.296	0.025
12.	Malsai	-	0.1903	0.011	0.018	0.0151	0.0343	0.014	0.176	0.027
13.	Charra	0.308	0.0429	0.456	0.027	0.0197	0.0429	0.037	0.561	0.025
14.	Atrauli	0.623	0.1025	0.106	0.033	0.0203	0.0526	0.137	2.012	0.039
15.	Gorha	0.143	0.2123	0.172	0.021	0.0245	0.0397	0.028	0.361	0.024
16.	Bilram	0.345	0.0220	0.074	0.026	0.0150	0.0397	0.018	0.393	0.022
17.	Naugawan	0.482	0.0952	0.063	0.032	0.0194	0.0418	0	0.246	0.020
18.	Ikhauna	1.396	0.1830	0.484	0.106	0.0217	0.0636	0.434	1.090	0.033
19.	Ghinauna	0.829	0.1903	0.065	0.040	0.0172	0.0519	0.387	0.372	0.015
20.	Wahidpur	0.966	0.1537	0.127	0.029	0.0265	0.0339	0.054	0.008	0.016
21.	Narauli	0.286	0.1757	0.084	0.035	0.0189	0.0530	0.157	1.094	0.026
22.	Barwari Kalan	0.306	0.0293	0.079	0.041	0.0250	0.0318	0.227	0.222	0.017
23.	Namaini	0.171	0.2399	0.056	0.035	0.0182	0.0392	0.066	0.789	0.025
24.	Saleempur	0.37	0.1949	0.011	0.031	0.0107	0.0328	0.030	0.311	0.018
25.	Kahairpur	1.087	0.1649	0.099	0.058	0.0339	0.0487	0.076	0.144	0.023
26.	Soron	1.685	0.4723	0.067	0.060	0.0078	0.0741	0.586	0.758	0.018
27.	Kasganj	1.92	0.8546	0.013	0.0086	0.0425	0.1165	0.76	1.305	0.020

APPENDIX - IX (B)

Trace element data of water samples collected from deep tubewells in the study area.

(Result in mg/litre)

Sl. No.	Location	Fe	Pb	Zn	Cu	Cd	Cr	Mn	Sr	Li
1.	Ganeshpur	-	0.2380	0.013	0.022	0.0153	0.0601	0.010	0.007	0.035
2.	Atrauli	0.346	0.0210	0.014	0.013	0.0102	0.0310	0.051	0.276	0.012
3.	Gazipur	-	0.0201m	0.032	-	0.002	0.0240	0.011	0.125	0.007
4.	Gangiri	0.082	-	0.027	0.032	0.0151	0.0429	0.024	0.309	0.017
5.	Charra	0.108	0.0120	0.034	0.031	0.0081	0.0135	0.016	0.446	0.001
6.	Bilram	0.145	0.0120	0.071	0.032	0.0120	0.0097	0.018	0.334	0.012
7.	Naugaon	0.066	-	0.024	0.027	0.0266	0.0381	0.038	0.994	0.017
8.	Kasganj	0.192	0.1680	0.099	0.042	0.01250	0.065	0.076	0.867	0.02
9.	Soron	0.035	0.2324	0.013	0.037	0.0333	0.0381	0.033	0.464	0.015

APPENDIX - X A

Results of Partial chemical analysis of water samples collected from dug wells of the study area during 1989

(Result in mg/litre)

Sl. No.	Location	pH	E.C.	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Na^+	K^+	Ca	Mg	T.D.S.	Total hardness
1.	Rukhela	8.0	513	12	350	63.9	200	114.3	68	40	29.0	328	200
2.	Surajpur	7.5	350	6	250	60	75	43	27	34	23	230	180
3.	Ganiawali	7.62	827	6	300	56.48	130	139.2	17.7	29.34	18	520	145
4.	Atrauli	7.9	510	6	290	65	90	80	30	35	27	320	200
5.	Sunhera	8.0	490	9	300	46.15	100	30	83.2	44	32.58	313.6	170
6.	Narauli	7.8	554	15	333	85.2	102	61.2	29.4	60	34	355	133
7.	Sirawali	7.8	345	21	348	43	110	60	28.3	38	27	225	210
8.	Ikhauna	7.6	1057	15	400	142	110	111.2	135.3	35	41.12	688	220
9.	Soron	7.7	573	6	412	49	100	65	24	50	46	380	180
10.	Kasganj	7.5	710	21	268	56	160	34.3	24	60	35	450	295

APPENDIX - X (B)

Results of partial analysis of water samples collected from dug wells of study area during 1989.

(Result in epm)

Sl. No.	Location	pH	E.C.	CO_3^{--}	HCO_3^{--}	Cl^-	SO_4^{--}	Total	Na^+	K^+	Ca^{++}	Mg^{++}	Total	Na%	SAR	R.C.
1.	Rukhela	8.0	513	0.4	5.7	1.80	4.16	12.06	4.97	1.7	2.00	2.30	11.06	60.0	3.35	1.78
2.	Surajpur	7.5	350	0.2	4.1	1.69	1.56	7.55	1.86	0.69	1.69	1.89	6.13	41.00	1.39	0.72
3.	Ganiawali	7.6	827	0.2	4.91	1.59	2.7	9.40	6.05	0.45	1.46	1.48	9.44	68	5	2.17
4.	Atrauli	7.9	510	0.2	4.75	1.83	1.87	8.65	3.47	0.76	1.74	2.2	8.17	51.7	2.47	1.01
5.	Sunhera	8.0	490	0.3	4.91	1.29	2.08	8.58	1.30	2.12	2.19	2.7	8.31	41.2	0.83	0.32
6.	Narauli	7.8	554	0.5	5.45	2.4	2.1	10.45	2.86	0.75	3	2.8	9.41	30.39	2.1	0.15
7.	Sirawali	7.8	345	0.7	5.7	1.21	2.29	9.9	2.60	0.71	1.9	2.22	7.43	44.54	1.81	2.3
8.	Ikhauna	7.6	1057	0.5	6.55	4.00	2.30	13.35	4.83	3.46	1.74	3.38	13.41	61.00	3.01	1.93
9.	Soron	7.7	573	0.2	6.75	1.38	2.08	10.41	2.83	0.6	2.5	3.8	9.73	35.36	1.60	0.65
10.	Kasganj	7.5	710	0.7	4.4	1.57	3.3	9.97	1.5	0.61	3.0	2.87	7.98	26.37	0.87	1.45

APPENDIX - XI (A)

Results of partial chemical analysis of the surface water bodies collected from selected stations, during june 1988.

Ganga River

Location	p^H	E.C.*	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Na^+	K^+	Ca^{++}	Mg^{++}	T.D.S.	Total hardness
Dinapur	7.5	153	-	130	14	5	6.7	3.2	25.6	5	97.92	85
Sankra	7.65	170	-	180	18	12.5	6.85	3.5	25.0	10	108.00	103
Ismailpur	8.00	210	5	175	24	15.0	8.00	4.02	28.0	9.5	125.00	105

Kali river (Result in mg/l)

Location	p^H	EC^*	CO_3^{--}	HCO_3^-	Cl^-	Na^+	K^+	Ca^{++}	Mg^{++}	SO_4^{--}	$CaCO_3$	TDS
Atrauli Road	7.51	471	35	397	53	39	13	56	25	139	144	301
Gaonkhera	7.81	502		330	38	63	15	59	28	85	256	321
Sunahra	7.74	485	15	342	42	55	13	62	32	132	280	310
Parora	7.76	496	15	595	58	48	14	140	62	148	400	380
Hidramai	7.82	510	30	485	53	58	13	56	26	144	144	310
Badhari Kalan	7.71	484	18	439	60	65	11	240	108	113	740	281
Firozpur	7.96	495	12	752	63	62	11	192	86	31	420	481

*E.C. measured in micromohos/cm at 25°C.

Lower Ganga canal (Result in mg/l)

Location	p^H	E.C.	CO_3^{--}	HCO_3^-	Cl^-	SO_4^-	Na^+	K^+	Ca^{++}	Mg^{++}	TDS	Total hardness
Sankra	7.6	127	-	183	31.61	10	8.00	5.00	31.18	8.5	90	110
Kasganj	8.0	140	-	190	38.56	15	6.49	6.8	32.01	10.0	946	117

APPENDIX XI (B)

Trace Elements Data (by A.A.S.) of the surface water bodies collected from selected stations.

Ganga River

Location	Fe	Cu	Pb	Cd	Mn	Cr	Li
Dinapur	0.58	0.06	0.164	0.005	0.652	0.038	0.028
Sankra	1.68	0.40	0.170	0.056	0.674	0.038	0.040
Ismailpur	1.82	0.35	0.185	0.070	0.660	0.040	0.031

Kali River

Location	Fe	Cu	Zn	Mn	Cd	Cr	Pb
Atrauli Road	0.110	0.236	0.022	0.048	0.021	0.074	0.022
Gaonkhera	0.141	0.146	0.020	0.036	0.003	0.004	0.078
Sunahra	0.178	0.186	0.066	0.062	0.006	0.042	0.078
Parora	0.328	0.462	0.032	0.060	0.004	0.122	0.990
Hidramai	0.095	0.321	0.094	0.012	0.029	0.162	0.007
Badhari Kalan	0.135	0.126	0.044	0.112	0.027	0.062	0.095
Firozpur	0.109	0.246	0.039	0.074	0.022	0.034	0.148

Lower Ganga Canal (Result in mg/l)

Location	Fe	Cu	Pb	Cd	Mn	Cr	Li
Sankra	0.326	0.421	0.09	0.041	0.068	0.05	0.03
Kasganj	0.346	0.500	0.10	0.001	0.090	-	0.032